1. Conversations, Models, and Individuals

The last chapter contained a brief but truthful account of a man—machine system for realising a limited but non-trivial conversation. Attention was focused upon two sorts of conversation associated with distinct regulating heuristics; namely conversations for exhibiting or externalising learning and problem solving strategies in a minimally biased fashion (the CET heuristic) and tutorial conversations governed by an uncertainty regulating (tutorial) heuristic. In both cases, the topic of the conversation, formally, its domain was fixed and characterised by a paired description of knowable relations; namely, the entailment structure and the task structure. The conversation took place within a normative framework (the experimental/tutorial contract) in which the student agreed to "speak" an object language (the command and question language of CASTE); though the contract itself was negotiated in the metalanguage of an external observer. In the sequel, we refer to the CASTE language, or any other object language with its capabilities, as L; and to the metalanguage as L*.

1.1. *Contracts.* For his part in the contract, one participant, the student, (A of Fig. 1 or Fig. 2, in Chapter 4) agrees to obey the L syntax to the extent of accepting corrections from another participant B (the heuristic) as mandatory; next, he agrees either to aim for and bring about a relation R_i in the conversational domain or, failing that, to aim for the learning goal of constructing a procedure, alias a concept, which permits him to do so. (Proc i in the notation used in the caption to Fig. 2 of Chapter 4). Hence, the language L has a full *semiotic;* that is a syntax, a semantic interpretation with respect to the domain and a pragmatic interpretation. For a particular contract these slots are filled by naming a specific domain (such as elementary probability theory) and a specific class of intentions for example, in the tutorial conversation, that A will play the role of a student.

1.2. *Occasions and understanding.* The conversation, as witnessed by the strategy records of Plate 6 or Plate 7 in Chapter 4, takes place over a series of occasions, each indexed by an integer, n, one to each frame in the figure. Any occasion is characterised by a recognisable linguistic event; namely, the occurrence of an understanding of some topic relation in the domain, and the conversation goes on until all the knowables in the domain are learned. The condition recognised as understanding is the correct explanation of whatever topic relation, R_i, is addressed on the occasion in question (which is evidence for a concept of R_i, called $\underline{Proc}^0 i$, in A's repertoire) and also the explanation of how R_i is explained (which is evidence for the existence of a memory of R_i, namely a procedure $\underline{Proc}^1 i$ in A's repertoire). The event "understanding" was compared to the existence of "teachback" described in Chapter 3 but in CASTE, the condition is mechanically detected by the heuristic. It is noteworthy that evidence for the explanation of an explanation generally exists before the explanation i.e. that B "knows how A will explain R_i" (by reference to A's strategy) before B "knows whether or not A can give a correct explanation of R_i"; in teachback, this order of precedence is usually reversed i.e. the human version of B relies upon A's retrospective account of his own mentation.

1.3. *Strict conversations and the CET heuristic.* The modes of man–machine conversation so far reviewed are called strict conversations because the following conditions are satisfied: (1) All topics R_i belong to a fixed domain, R, on which the conversation is anchored; (2) Understandings are recognised and used to demarcate occasions which are placed in order 0, 1, . . .n . . .N.

The basic CASTE operation is carried out by the CET heuristic which is founded on the idea that A is designed to learn (in the sense that if A is unable to explain a topic R_i, picked out by B, then he aims to construct a concept, $\underline{Proc}^0_A i$ which will explain R_i) and also upon a series of assumptions about A and the conversational domain, R, which guarantee that understanding, once achieved, persists while the conversation is anchored on R (because of which, the understanding markers in CASTE are indellible).

1.3.1. There are two sub-operations; to recognise the end of an occasion and to constrain the actions of A so that the following conditions are all satisfied.

1.3.2. (a) Another occasion begins (unless all topics in the domain are learned). (b) The next ostended topic(s) belongs to the domain. (c) The topic ostended (R_i) is not already understood. (d) R_i is a topic such that if A can furnish a correct explanation of R_i, then he has already indicated (by his strategy up to this point) how he explains that explanation. (e) If not, then A will interpret the directive to bring about R_i as an instruction to construct an L procedure or concept, $\underline{Proc}^0_A i$ for this purpose. (f) If A cannot obey this instruction B can and will provide information that allows A to do so.

1.4. *Details.* The heuristic required to perform this operation is shown explicitly, as the annotated programme listing, in Appendix D. The tutorial heuristics described in the last chapter, are obtained by periodically evaluating the macro grain variables θ and H (of "CASTE") and regulating the dialogue so that certain macrotheoretic boundary conditions are approximated. To complete the record, the task structure procedures are also shown explicitly as augmenting routines in Appendix E (the operation of BOSS, the belief and opinion sampling system, is taken for granted, since this system is a peripheral unit with its own computing facility).

1.5. *Extensions of the strict conversation.* Two important extrapolations of the strict conversational modes were mentioned but not discussed in the last chapter.

1.5.1. One of these extrapolations, necessary if CASTE is employed for course assembly, permits the evolution of the conversational domain R; that is $R = R(n)$. Under these circumstances, A plays the role of "subject matter expert" rather than, or as well as, "student" and he is allowed to operate upon the domain itself, by adding nodes to the entailment structure and substructures to the task structure. Any student acting creatively would occupy this role from time to time and precisely the same arrangements can be used for course assembly and the experimental study of innovation. Even so, if understandings are to be recognised and occasions to be ordered, the evolution of the conversational domain must be systematic. In particular, conditions are imposed upon the nodes added to the entailment structure and to the substructures joined to the task structure.

The main requirement is to give a precise account (which exists) of what an entailment structure is; namely a connected, cyclic and consistent mesh of relations together with a family of L descriptions (Plate 3 of Chapter 4 is one member of the family attached to one such mesh). Once the necessary rules are formulated, they are quite easily embodied in regulating routines that are dually interpretable (a) in the context of course assembly as devices for encouraging the generation of knowables or (b) in the context of instruction, as teaching devices that allow the student to choose amongst a family of descriptions (and which can, in principle, make use of information about the description(s) he selects). Though evolutionary conversations of this type are operationally characterised in the present chapter the task of stipulating the rules and detailing the processes is deferred until Chapter 7.

1.5.2. The other extrapolation is more fundamental. So far, there has been no representation of A or B as part of the conversational domain; only of subject matter topics that amount to an expert's theory. But A can play the part of expert when R = R (n). Consequently, it makes sense to enquire whether or not A could inscribe his model of B upon the domain and, vice versa, B his model of A; further, to enquire whether the process can be iterated to yield A's model of B as part of the domain.

With certain minor caveats the answer to both questions is in the affirmative; moreover, for many situations these descriptions form a closed and coherent system.

1.6. *Reasons for developing a theory of conversations.* In Chapter 4 the reader was asked to accept a great deal as an act of faith; reasonably so, because each facet of the abstract argument was embodied in some tangible working device or supported by empirical data. If the CASTE facility were no more than a fancy experimental/teaching/course assembly system, we might leave it at that. However, there are several reasons for proceeding further; they are cited below because the labour of comprehension is appreciable enough to need justification.

For example, since CASTE does teach very efficiently (dramatically so, if the results are presented to highlight this fact) we might ask why it works. It is a mechanism, after all, and as a result, this why-question can be answered at more than an intuitive level. Again, it would be difficult to design variants on CASTE (which is manifestly worthwhile) without having a

theoretical foundation to account for its operation. Finally, as a matter of historical fact, CASTE was not built as a sophisticated piece of laboratory equipment. True, it was expected to work. But it was constructed because it (together with the extensions mentioned in the last few paragraphs) embodies a theory of learning and teaching and cognition in general.

The strict conversation is a near minimal paradigm from which to start the discussion. But the theory itself applies to all conversations and, given the stricture that a conversation is the minimal unit for psychological observation, all of psychology (including its extrapolation into related areas of education, sociology, social anthropology, and the ecology of sentient beings; for example, architecture, as it deals with cities that are lived in; or information-science, with the rider that information is used whereas data is stored).

The argument culminates in an account of the understanding condition that is recognised by a CET heuristic and used to demarcate an occasion. During the discussion it is both possible and necessary to generalise the conversational paradigm to specify a series of special forms of this general representation, to interpret each one as the image of a class of experimental situations and to show, as claimed earlier, that the theory which underpins these situations is an adequate psychology.

The theory expounded is primarily a micro grain or "molecular" theory of conversations, (Chapter 2, Section 5) which specifies structures and organisations. The macro grain or "molar" theory (Chapter 2, Section 4) deals with "self-organisation". For completeness, the ossature of the uncertainty regulation heuristic (which employs the macrotheoretic uncertainty indices H, θ and H*, θ*, as control variables) is discussed in Chapter 6. But a description of the macrotheory proper, and of the challenging problems that crop up when the macrotheory is brought into correspondence with the microtheory, is postponed until Chapter 11.

1.7. *Foundations.* The basic units of a strict conversation in a language, L, are relations, R_i, with names "i". Functions are specially restricted relations (one to one or many to one relations) and are treated uniformly. The L description of R_i is D(R) and is a grammar-like, permission-giving, structure which states how R_i

may be satisfied. A relation R_i is said to be m-adic or of order m if it unites m distinct properties; a 1-adic relation is a property[4].

The notion of a relation (including the limiting instance of a property) is two faceted. From one point of view, germane to physics and mechanics, a relation is a quality possessed by certain configurations of things and not by others or which has distinct (perhaps numerical or quantitive) values with respect to distinct configurations in a fixed universe. In language, this viewpoint leads to an adjectival usage. From another point of view a relation (again including a property) is a procedure which, if executed in a certain universe, operates upon it to bring about or maintain a configuration or which, when presented with a given configuration, may or may not operate (a test, in other words. If the configuration does satisfy the tested condition it is replicated unchanged). The latter point of view is germane to psychology and leads to the linguistic notion of relations as verbs.

[4] Though it would be out of place to argue the point at length in this context this seemingly harmless notion bites at several cherished ground rules of scientific argument and it may be useful to indicate the flavour of the underlying philosophy. For example, one often resorts to the idea of an "unordered set" as somehow elementary. According to this theory (which is in accord with common experience though not with technical parlance) no such thing was ever perceived; in particular, no such thing (though it can be and is conceived) is conceptually primitive or "simple". As a matter of fact, we usually introduce the notion of an unordered set by pointing to a relation, between tea cups on a table, say. Next, we note that apart from the relations that lead us to say they are unitary (because they are all round, made of pottery, and so on), they (as units) are arranged in a rectangle, below the chandelier, above the legs of the table. Next, we ask the listeners to conceive all relations like these (an indefinite number) and to discount them; next, to discount the particular relations "above" or "rectangularly arranged"; next, to discount the relations whereby the teacups are unitary "objects" that may be patterned in a way that has just been discounted by edict; next, to discount the relations whereby these ghostly remnants of (relational) objects are other than tags (i.e. we have reduced the teacups to an alphabet like A, B, ...; have removed the lexicographic ordering whereby the alphabet is known and all features of the signs A, B. . . . . except those that keep them distinct). Finally, we rescind the relation "set of alternatives" (over distinct tags). This "unordered set" is such an abstract, purely imaginary, entity that, without detriment, we may impose upon it whatever relation we like to invent. Thus teacups are psychologically real (the theory is not solipsistic) and the objects in an unordered set are psychologically real. But when instancing a set by pointing at real entities we are not, whatever else may be done, pointing at objects.

To render these ideas more precise consider the language L; the conversational object language. An m-adic relation R_i is designated adjectivally by an m-place L-predicate; Pred i $(s_1 \ldots s_m)$, where $s_1 \ldots s_m$ are object variables in L, and Pred i appears in expressions together with the verb "is" of "assignment". Under these circumstances, the execution of a procedure is tactily referenced: Pred i holds for entities in the universe of interpretation of L because a procedure that maintains R_i is executed iteratively. The adicity of R_i specifies the number of variables or coordinates cited in the same expression to state the condition and the irreducible or minimal adicity of R_i specifies the number that must be cited in order to do so. R_i is designated explicitly as a verb by a procedure Proc i written in L to be executed in an L processor. The execution of a function (one to one or many to one relation) corresponds to the imperative/indicative mood of verb usage; the execution of a relation (other than a function) may (and usually does) involve the conditional/subjunctive mood of verb usage. The irreducible adicity of R_i is the number of loci of control that such an L processor must accommodate at once.

The mathematical and logical representations of a relation are derived as an abstraction from this picture. An intension of R_i is a class of procedures able to compute R_i and an extension of R_i is a standard model for R_i. To derive the extension, each related property or coordinate of R_i is identified with a set of elements $s \in S_j$ with $j \in J$ an index set. The field of R_i (the union of its domain(s) and codomains(s)) is $\bigcup_{j \in J} (S_j)$ and R_i is expressed as a subset of the cartesian product $S_1 x \ldots x S_m$; $j = 1, \ldots, m$, so that $< s_1, \ldots, s_m > \in R_i \subset S_1 x \ldots x S_m$, the Universe of modelling.

1.7.1. Since the general intension of R_i is frequently unbounded, it has little immediate interest. Suppose, however that it is possible to distinguish individuals, A, B (leaving open the question of how A and B are distinguished). In this case A's (subjective) intension of R_i is a repertoire Proc^0_A i. Given an L processor and the name i of R_i as a command, a repertoire is executed to generate a model. For example, concentrating upon Proc^0_A i, its execution generates a model M_A i that is one of A's extensions of R_i.

The model in question may be abstract or concrete depending upon whether the environment of Proc^0_A i is a set of storage locations (holding values of the object variables s_j of L) or a modelling facility such as STATLAB in CASTE in which parts are identified as elements of a universe of modelling selected by $\underline{\text{Proc}}^0_A$ i. That is[5], if X stands for the set of parts in a modelling facility, if a^0, b^0, etc. stand for partially built models then $\underline{\text{Proc}}^0_A i(X) = \langle a^0, b^0, \ldots M_A i \rangle$ (provided that it is possible to instantiate R_i in the facility) and $\underline{\text{Proc}}^0_A i (M_A i) = M_A i$.

Since $\underline{\text{Proc}}^0_A$ i generally consists in several procedures, there are generally several models of R_i namely $M_A k,i$ and $M_A l,i$; synthesised by $\underline{\text{Proc}}_A$ k, i and $\underline{\text{Proc}}_A$ l,i. In each case, the first step delineates a specific universe (X_A which is a subset of X). Similarly, the application of any $\underline{\text{Proc}}^0_B$ initially establishes the corresponding B universe X_B. So far as A and B are concerned the field of R_i is identified (on the nth occasion) with the universe X_A and X_B. In other words, A and B are free to select their own universes of modelling (perhaps within certain constraints, such as the limited number of event sockets or result sockets on STATLAB), but subject to the overriding restriction that any model built in the facility must belong to a given *class* M; for example, the class of finite automata, or the class of mappings or a group or a semigroup. We shall also insist that any model constructed with a special facility such as STATLAB is built up in steps occurring at distinct instants, $t = 0, 1, \ldots$ Hence the operation of $\underline{\text{Proc}}^0_A$ i (for example) may be represented as the serial application of operators $y \in Y$ (where Y belongs to a mapping from the power set of X onto X; that is $Y \subset (Ps(X x X))$. Notice, this seriality condition is not applied to all models; merely to those constructed in a specially reserved modelling facility.

1.7.2. This conception of modelling is at odds with some precepts of cognitive psychology where it is usual for the experimenter to give certain properties to which respondents are

[5] It should be noted that this formulation is deliberate and designed to accommodate the following kind of possibility. X may be a set of conditions of an organism's physiological fabric; its nervous system, sensors, limbs, etc., for example. If so, the constraint M is structural (biomechanical); further, as mooted explicitly in Section 2.5.8, the act of "performing a skill" is imaged as making a model (usually in the brain and body, maybe augmented by sensory, motor or computational equipment external to the organism) which is subsequently executed under the control of a (biological) τ clock on a par with the τ clock in any other modelling facility.

supposed to attend; for example, the defining attributes of a universe of Bruner Cards, like colour, size and shape. In the theory of strict conversations, individuals are required to select their own universe and place its elements in correspondence with the field of R_i; though A and B may select any universe that might be employed in a standard experiment; also A may ask B to attend to a specific universe or vice versa. The distinctive difference is that in a standard experiment predication lies outside the proceedings (the experimenter selects and asserts the L predicates and the properties they denote); in the conversational situation, predication figures as a crucial part of the dialogue and is due to the participants.

Although the act of predication is not discarded as irrelevant by standard psychology, it usually either remains unmentioned or is assigned to a special compartment of attention studies[6]. In outstanding exception is the brand of psychology (Kelly 1955 Bannister and Mair 1968) concerned with personal constructs which are produced by predication and are frequently elicited by the repertory grid technique.

1.7.3. Another departure from the standard approach is marked by the fact that M_A i and M_B i may either be static or dynamic models. As in the case of predication, there is no real dispute or disparity between standard psychology and the present theory since it is fairly uncontentious to say that any relation must be maintained if it is to persist. Only sometimes it is legitimate not to mention the mechanism that maintains it; when, for example,

[6] Rightly, in a sense, since predication is attention. But the majority of attention studies beg the real question by assuming that man is furnished with a great variety of perceptual filters from which selections are made when someone "directs his attention". The trouble, here, is that a brain is implicitly tagged as a special purpose computer with prescribed though redundant input, rather than a general purpose computer for which input and programme variables must be declared. Hence, the genesis of relevance is consigned, in turn, to biological or developmental studies. Computer scientists generally view the matter differently. Since they deal with general purpose (programmable) machines they appreciate that variables must be declared and that in order to declare them there must be (beforehand) a relation in mind which is instantiated by identifying its field with the universe of these variables. But, of course, it is the programmer who declares the variables (in much the same way that the experimenter declares the attributes in standard cognitive psychology). Our development places the act of predication inside the conversation rather than outside it.

there is a principle of invariance or when the elements of a universe are inherently stable (a fact mathematically imaged by attaching an identity operation to each one). So, for example, the relations "North of" and "rectangular" are legitimately given static models insofar as they are instantiated in terms of objects that remain fixed in space once they are positioned. Other relations are explicitly preserved by executing some operation; for instance, the relation between room temperature and a thermostat setting is maintained by a central heating system and, in general, such relations are stabilised by a control mechanism that expresses the relation. Here, a model for the relation (one of its extensions) is dynamic and is executed in time so that R_i (in this case quite explicitly) holds over a period of time. Whereas standard psychology usually takes the legitimacy of a static model for granted, one cannot afford to do so when discussing strict conversations and the explanatory facet of dialogue.

1.7.4. The distinction between static and dynamic models is artificial since all models should, strictly, be dynamic. Static modelling is a convenient shorthand form of representation and no more than that. Provided this fact is recognised the use of static models, where they are legitimate, avoids a great deal of cumbersome symbolism.

The following examples use the relation "⊕" or "add modulo 4" as a vehicle for illustrating both the static/dynamic distinction of immediate concern and the general notion of a universe of modelling. One model of "⊕" (A's perhaps) is defined over a limited universe of integers. Its extension, Table 1, is a list of all triples $\langle s_a, s_b, s_c \rangle \in S_a \times S_b \times S_c$ of all integers x in S_r; r = a, b, c, $S_r = \{1, 2, 3\}$ for which the relation holds.

This figure might be drawn in terms of numerals, simply distinct from one another, and members of a relation on ({1, 2, 3}) called "set of alternatives". As it is, however, the triples have been structured by assigning the term *sum* to the last coordinate (or column) S_c and the term *summands* to the first pair $\langle S_a, S_b \rangle$. Moreover the values of each coordinate have been structured under a successor operation and it is thus possible to assert that $3 > 2 > 1$. The model is readily generalised so that it represents "+" of any modulus over an arbitrary number system (integers, rationals, reals) which might be B's universe. But the weak version is illuminating insofar as it typifies the kind of relation that holds

TABLE 5.1
Addition of Remainders Modulo 4, symbolised ⊕, and the 3-tuples that satisfy this relation. Notice that the co-ordinates of the relation may be more or less specialised; that is, any co-ordinate may have a relation (such as 'successor of') assigned to it and as a result it may be structured.

Addition Table For ⊕

⊕	0	1	2	3
0	0	1	2	3
1	1	2	3	0
2	2	3	0	1
3	3	0	1	2

Set of 3-tuples satisfying the relation ⊕
a triadic relation

Universe of ⊕ is $S_A \times S_B \times S_C$

Summands S_A	S_B	Sum S_C
<0	0	0>
<0	1	1>
<1	0	1>
<0	2	2>
<2	0	2>
<0	3	3>
<3	0	3>
<1	1	2>
<1	2	3>
<2	1	3>
<1	3	0>
<3	1	0>
<2	1	3>
<2	2	0>
<2	3	1>
<3	2	1>
<3	3	2>

over non mathematical fields. For example, kings of a country are distinct and chronologically ordered and related to other monarchs, dynasties and so on.

A dynamic model for the relation "⊕" is an adding machine. This, of course, is a process.

The process may be represented, canonically, as a finite automaton (clearly there are many addition methods and thus finite automata that add, but all of these specific models are extensionally equivalent, since they realise R_i = "⊕"). The model is dynamic insofar as, given any pair of inputs at instant τ it outputs the sum at instant $\tau+1$, thus maintaining stable the condition that R_i holds over any interval $\tau, \tau+1$ where $\tau \in T$ and $\tau+1 \in T$. The unspecific extension of $R_i = \oplus$ (Modulo 4) is obtained by structuring the coordinates so that the first pair is labelled τ and the last column entry is labelled $\tau+1$. Notice that addition is either regarded as immaterialised, or some such trick as τ labelling is played in respect of elements in the universe. For instance, the trick played in set theory is to regard elements as integral (the identity axiom) and relations as atemporal. An index such as $\tau \in T$ has the effect of materialising addition in a less abstract but still very restricted fashion (the assumption that values of τ are strictly ordered asserts, in effect, that the universe is a finite state machine).

A specific machine (a finite automaton) can also be represented in extension, for example by a set of quadruples.

Input state at τ (the first pair in Table 1 or its generalisation)	Internal state, at τ	Internal state, at $\tau+1$	Output state at $\tau+1$ (the last entry in Table 1 or its generalisation)

or, for terminology

$$\tau.\ \langle u_\tau, z_\tau, z_{\tau+1}, v_{\tau+1} \rangle$$

($u \in U$ Input states; $z \in Z$ internal states; $v \in V$ output states; $\tau \in T$ trial order). This account is clearly much more concise than a generalised function Table drawn (impracticably) for "all integers" or "all real numbers". However, it is also, necessarily, more specific. The modelling facility must be meaningfully structured to represent states, each of which (since one and only one state occurs at once) is a member of a set of alternates (itself, recall, a relation). Concisely, any model of this type belongs to a certain class, here the class of finite state machines. A specific state $x \in X$ (or $x \in X_A$ or $x \in X_B$) is a quadruple.

$$x = \langle u_\tau, z_\tau, z_{\tau+1}, v_{\tau+1} \rangle$$

a specific machine, say the lth machine, is a set of quadruples

$$X_l = \{x\}_l = \{\langle u_\tau, z_\tau, z_{\tau+1}, v_{\tau+1} \rangle_l\}$$

such that any $x \in \{x\}_l$ is a member of a mapping pair

$F_{l,i}$; $U \times Z \times T \rightarrow V$ (next output state function)

$G_{l,i}$; $U \times Z \times T \rightarrow Z$ (next Internal State Function)

If the class of models that may be built in a facility is the class of finite state machines then this is a detailed description of the constraint introduced in Section 1.7.1, that any model must be a member of the class M. Notably it is quite legitimate, in a modelling facility, to reduce the specificity either by projecting a relation onto one or more of its coordinates, or by assigning a constant value to any one coordinate. For example, if $z = z_0$ for all $z \in Z$ then M accommodates dynamic mappings (in Ashby's sense 'Black Box' models); if $\tau_r = \tau_0$ for all $\tau \in T$, also, then M accommodates all mappings such as atemporal function specifications.

1.7.5. The symbol τ is deliberately reserved for an index over steps or trials in the execution of a dynamic model in contrast to the index t (Section 1.7.1) over the instants at which $\underline{\text{Proc}_A}$ i or $\underline{\text{Proc}_B}$ i is executed. Thus τ represents the output of a facility clock, like the input tape oscillator in STATLAB or the execution act of pressing one result button. In contrast t represents the output of a clock that progresses by one unit for any stage in modelling.

1.7.5.1. We generally insist (though, as later, the restriction is not essential) that the τ clock is zeroed ($\tau = 0$) if t changes in value. In other words, if a dynamic model is executed ($\tau > 0$) then model building ceases, and if modelling operations are in progress, then the trials clock is stopped and zeroed. These constraints secure a structure/function distinction and preclude, amongst other things, the possibility of models that act upon themselves. If these constraints are imposed, a modelling operation can be expressed by a series. The lth model M_A l,i, built by A at instant t during the nth occasion is $M_A l,i = \{x\}_{li} = \{x\}_l^t = Y_t(Y_{t-1}(\ldots . Y_1(Y_0(X))\ldots))$ obviously (as in CASTE) the model $\{x\}_t$ may be executed ($\tau > 0$) and, if necessary, modified to produce further models $\{x\}_{t+r}$, $r > 0$, before a model is finalised.

1.7.5.2. Two important types of clocking constraint are exhibited in Fig. 1 and Fig. 2. As before, t is the index of a

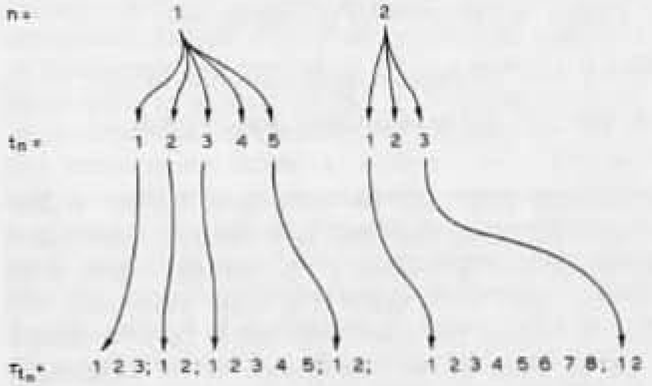


Fig. 5.1. "Clocking" constraints maintaining structure/function distinction as used in simplest type of modelling facility.

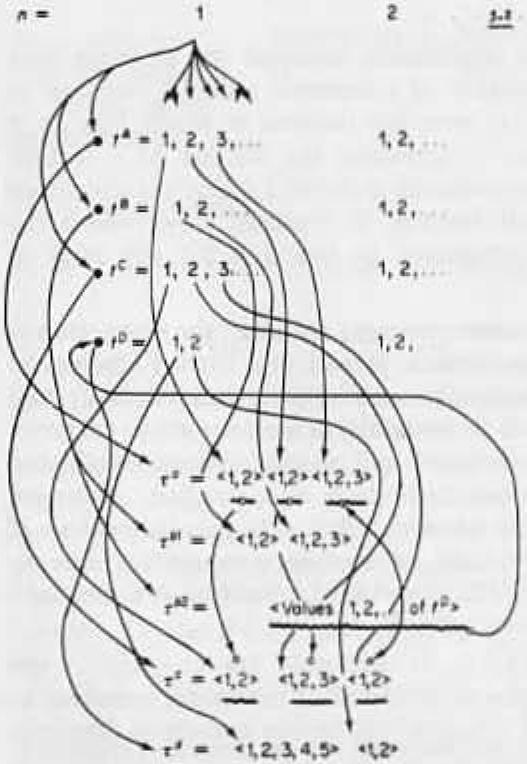


Fig. 5.2. The most liberal "Clocking" constraints readily permissible.

modelling (or operating) clock and τ the index of a model execution clock. But there may be more than one of each.

1.7.5.3. In Fig. 1, which preserves the structure/function distinction, there is one t clock and one τclock; further these are stopped and started as described in the last subsection, τ being zeroed if a fresh model is made (a segment of t values). Consequently, all t and τ segments not only belong to one and only one occasion, n, (so that they should properly be subscripted by n) but also they are linearly ordered in n. An external observer can locate the τth execution step in the t-th model of occasion n, as suggested by the notation τ_{tn} (for execution steps) and t_n (for modelling operations).

1.7.5.4. In Fig. 2 illustrating the opposite extreme, the maximum tolerable liberality, there are several clocks, t^A, t^B, ... so that models can be built concurrently and (if desired) independently, since the t clocks are specified as asynchronous (being moved on by modelling operations) unless they become synchronised by virtue of the model maker's actions.

Similarly there are several (unless otherwise prescribed asynchronous) model execution clocks labelled τ^a, τ^b, . . . , so that the models made under t^A, t^B .... can be executed in parallel (some t may have several τ; for example, t^B has τ^{b1}, τ^{b2}) independently of the model maker. The only caveat is that a change of model, that changes t^A, also zeros τ^a and that a change of t^B zeros whatever is only attached to t^B (in this case τ^{b1} only, since τ^{b2} is also in receipt of an input from elsewhere).

1.7.5.5. Two kinds of interaction can arise in such a system: (1) The operation of τ^a and of τ^c is synchronised because of communication between separately constructed models equipped with initially unsynchronised execution clocks. Later, we develop the fundamental point that information transfer, in an unusual but very relevant sense of that phrase, is uniquely correlated with synchronising (communicative) events, that are responsible for coalescing otherwise asynchronous systems. (2) As a rule, t clocks are regulated by the model maker (a participant). Since there may be several τ clocks to one t clock, an important facet of modelling is to recruit as many execution clocks as are required. The convention that t clock operation recruits or initiates execution (τ) clocks is retained but a special case (of appreciable significance) is shown by the illustrated connection from τ^{b2} (and model b) to the t clock, t^{D}. In other words, using the intermediary of a t clock, a model can make other models (t is usually advanced by modelling operations performed by a participant; here t^{D} is advanced by the modelling operations of model b2). Further execution clocks may thus be recruited[7].

1.7.5.6. In Fig. 2 all segments of the model making carried out and all segments of model execution belong to one and only one occasion n, but they are not linearly ordered in n, nor is there an obvious "ordering" of any kind (since in condition (2) we are tacitly assuming that τ^{b2} is a clock made by modelling and thereafter allowed to run on its own). However, all t clocks are zeroed when the occasion changes and thus all τ clocks are zeroed at the moment when understanding is detected. The important point is that other understandings may occur as a result of concurrent (and potentially communicative) activity in the modelling facility.

1.7.5.7. We do not, as previously emphasised, admit such liberally conceived modelling facilities. In fact, we remain with modelling facilities clocked like Fig. 1 because, for example, the strict connotation of state looses its meaning under the conditions of Fig. 2.

1.7.5.8. But so far as conversation is concerned, there is no objection to many clocked facilities and they are one stage removed from the many clocked L processors discussed later. These differ from Fig. 2 in only one respect; there is no requirement that an occasion shall have a beginning and an end; or that, clock-wise, there shall be an occasion.

1.7.6. In the sequel, it is assumed that any individual in a conversation has a matching operation which is continually available as a means of determining identity from this individual's point of view (formally, the matching operation is one of the primitive procedures, Prim, to be introduced as part of all cognitive repertoires). Any model either is or is not matched to some other model; in particular, it may or may not represent the

[7] Although the point is not pursued in depth, it will be noted, in Section 2, that the execution of a function/relation is tantamount to verb usage. Relations (other than functions) can be executed in the subjunctive mood as well as the imperative/indicative mood. To recruit execution clocks is (roughly) the meaning attached to subjunctive execution.

"same" relation R_i. Generally, there are two simple interpretations for the "same", depending upon how and when the matching operation is applied; namely, an identity of extensional equivalence (mooted already) and an identity of agreement. In a tutorial conversation, where polarity is imposed by the distinction between "teacher" and "student", there is also a real issue of whether or not a model is correct and (if it is correct) of whether or not it is also complete in the sense that it will bring about or satisfy R_i for all elements in a universe identified with elements in the field of R_i.

1.7.7. The demand for building a model is issued by a command; in essence, by an L programming edict. If the command is general, "make any model for R_i", it is dubbed a *Base* command. If the command is specialised (either "make a particular kind of model for R_i" or "make a model that does not contravene a class of boundary conditions" then it is qualified. In all cases, the command is addressed ("A! bring about R_i") to some individual (in this example, to A).

Suppose that A receives the base command "A bring about R_i" under conditions in which it is interpreted as "A make a model for R_i". Suppose, also, that A has a repertoire of procedures, $\underline{Proc}^{0}_{A}\, i$ for obeying this command; for example, $\underline{Proc}^{0}_{A}\, k, i$, and $\underline{Proc}^{0}_{A}\, l, i$, which are executed to produce two distinct models in the same universe of modelling (X_A) constrained to be members of the same class (M) and to be built in the same facility; $M_A\, k, i$ and $M_A\, l, i$. Even though the procedures $\underline{Proc}^{0}_{A}\, k, i$ and $\underline{Proc}^{0}_{A}\, l, i$ are, by prior definition, distinct (they are different subjective intensions of R_i) it is still possible that $M_A\, k,i$ and $M_A\, l,i$ are identical by matching, that is, each one can be executed in the facility (M) and each element of $M_A\, k,i$ corresponds to one and only one element of $M_A\, l,i$. If these conditions are satisfied $M_A\, k,i = M_A\, l,i$ and both $\underline{Proc}^{0}_{A}\, k,i$ and $\underline{Proc}^{0}_{A}\, l, i$ are said to be extensionally equivalent (which justified the initial assumption that they are both members of $\underline{Proc}^{0}_{A}\, i$). Further, a description of how to build the model $M_A\, i$ is also (in this case) a description of how A would bring about R_i and is derivable from a sufficiently broad account of how to bring about R_i. Assuming that the description $D^0(R_i)$ has this much generality, for each R_i in the conversational domain, R, derivability is signified by $D^0(R_i) \Rightarrow M_A\, i$.

1.7.8. In contrast, suppose that A and B are both commanded to bring about R_i in a facility limited by accommodating only class M models: that they are both able to do so, and that they build a pair of distinct models $M_A i$ and $M_B i$. Quite possibly A and B have different universes of modelling (X_A and X_B can be, and are likely to be, different). Consequently, it is improper to equate $M_A i$ and $M_B i$ as they may be distinct entities (they might even be built in different facilities). However, if both of them are evoked by a command to bring about the same relation R_i, then A has identified elements in his modelling universe (X_A) with the field of the relation R_i and B has identified elements in his (possibly different) modelling universe (X_B) with the field of R_i. Under these circumstances a one to one correspondence established by matching is an isomorphism signified by $M_A i \Leftrightarrow M_B i \subset M$ and, if this condition is satisfied, then A and B are said to be in exact agreement about their models. That is, A and B conceive the extension of R_i as the same relation even though they exhibit it in different universes of modelling (as, for example, the reader and I will have a common extensional meaning for words like "circular" and "great uncle" though we are likely to instance them quite distinctly). If A and B are in exact agreement, in respect of R_i, then there is at least one procedure in common that yields the same model, so that $D^0(R_i) \Rightarrow M_A i$ and $D^0(R_i) \Rightarrow M_B i$. In this sense, "A's intension of R_i" $\Leftrightarrow$ "B's intension of R_i" for some Proc in $\underline{Proc}^0_A i$ and some Proc in $\underline{Proc}^0_B i$.

The strict requirement of exact agreement can be waived, without detriment, insofar as the isomorphism "$\Leftrightarrow$" is replaced by an R_i preserving homomorphism and, if so, A and B are merely said to "agree with" each other about relation R_i. For exposition, however, it is convenient to restrict attention to isomorphisms.

Conversely, a rather deeper meaning is attached to agreement if the dialogue is engendered by a qualified command requiring that R_i is brought about by a particular class of procedure. If so, agreement involves intensional or programmatic equivalence. For example, one very strict criterion for agreement is to match the productions of A and B; namely (using superscripts to label the participants) to match each stage in (or each instant t in) a pair of modelling operations. That is to match A's operation

$$\underline{Proc}^0_A i\,(X) = \langle a^0_A,\ b^0_A, \ldots\ldots M_A i \rangle \text{ or (by seriality)}$$

$$M_A i = y^A_{t_A}\ (y^A_{t_A - 1}\ (\ldots\ldots (y^A_1\ (y^A_0\,(X))\ldots\ldots)\ )$$

with B's operation

$$\underline{Proc}^0_B i\,(X) = \langle a^0_B,\ b^0_B, \ldots\ldots M_B i \rangle \text{ or (by seriality)}$$

$$M_B i = y_{t_B}\ (y^B_{t_B - 1}\ (\ldots\ldots (y^A_1 , (y^A_0\ (X))\ \ldots\ldots)\ )$$

Such a naive matching is possible only if $t_A = t_B$. Using more sophisticated matching criteria, agreement/disagreement can be established, regardless of production length, provided that all productions are serial, or even provided they have a unique "beginning" and "ending" (for example, the TS program of STATLAB, Appendix E, which searches a solution tree). There is a further discussion of this matter in Appendix G.

1.7.9. The L statement form expressing "$M_A i \Leftrightarrow M_B i$" is an "L metaphor" which designates a material analogy and its context is expressible in the usual manner. For any pair of elements, α, β in the domain and codomain (field) of A's universe of modelling and any pair of elements γ, δ, in the domain and codomain of B's universe of modelling it is asserted that "α is to β as γ is to δ", in which one "is to" stands for R_i in A's universe and the other for R_i in B's universe and "as" stands for an analogical universe in which A's predication is meaningfully juxtaposed with B's predication; as a matter of agreement, due to the existence of a conversation involving both A and B[8].

1.7.10. It is important to realise that the notion of correctness in a tutorial conversation is a special case of agreement rather than veridiciality. One participant in a conversation in the role of teacher (conventionally B) is deemed an authority insofar as B is in possession of a cannonical theory; true or false, it does not matter. This dictum is reified (in CASTE, for example) by writing the theory as the conversational domain, R, and noting that its L description, $D^0(R)$, is, amongst other things, an account of how each R_i in R may be brought about. It is next pronounced that for each R_i in R the teacher's repertoire $Proc^0_B i$ is the execution of description $D^0(R_i)$ in some L processor. A normally permission-giving structure is thus taken in an imperative form. If A and B are both ordered, by a base command, to bring about R_i then the

[8] Similar comments apply to distinct fields predicated by the same individual; for example, the visual and the tactile fields of perception, in which the same figure may be given a visual and tactile representation.

agreement $M_A i \Leftrightarrow M_B i$ implies that A has made a correct model for R_i in the sense that $\underline{Proc^0_B}\, i\ (X) \equiv \underline{Execution}\ D^0(R_i)$ to produce a class of models $\{M_B i\}$ such that some $M_B i \Rightarrow M_A i$.

As before, qualified commands are more complicated. A teacher who issues a qualified command insists upon a measure of intensional agreement between an A modelling operation and some production obtained by executing $D^0(R_i)$. The TS routine for STATLAB (Appendix E) illustrates a current approach and is subject to the limitations already discussed. The student's modelling operation is matched stage by stage, or instant by instant, against the executions of $D(R_i)$ and agreement is inferred if and only if there is at least one exact match.

1.7.11. In aggregate, these comments indicate the calibre of the conversational object language, L. It is, as previously stated, a language with a domain of interpretation (R and the modelling facility) and a pragmatic content (A and B have roles, such as teacher and student). It is a command and question language, not just an assertoric language; it has predicate variables, their values being assigned by L users (in addition to fixed predicates), and it has temporal reference. The basic L statements are metaphors standing for analogies (rather than propositions standing for simple relations) and, operationally, agreement replaces veridical truth, though, as later, the notion of truth can be retrieved by a rather devious path (Chapter 11).

Finally, L differs from the run of formal languages, in being interpreted or given a semantics with respect to a conversational domain which is so constructed that any relation R_i, in R can be retrieved, without loss of specificity from other relations R_j, R_l, in R using only operations that are themselves represented in R; the representation D(R) containing a grammer-like or permission-giving substructure (D^1 (R) of Chapter 4) that says how any R may be known or constructed in this manner. As a result, any topic relation learned legally is also reproducible and L reproducibility replaces the more familiar idea of L true or derivable.

The other part of D(R) namely D^0 (R) is a description of R in terms of what may be done to bring about the relations R_i in R.

1.7.12. Any conversational domain, R, has several descriptions D^1 (R): often it has indefinitely many. For example, several descriptions are latent in Plate 3 of Chapter 4, (a) the description first emphasised, in terms of properties with values 1, 2, ... and

other properties with values A, B . . . . and (b) the entirely compatible but distinct description in terms of the distinctions "real"/"abstract" and "structural model"/"measure on a model". This pair of descriptors and others of the same ilk, preserve the distinctive subordination in the artificial hierarchy induced as part of the first classification scheme. Because of that, the descriptions (a) and (b) belong to the same family and may (for example) be jointly displayed as redundant accounts of the same structure.

If the reader will bear with a loose similitude between "the structure of knowledge" and a "two-dimensional projection of a city", it is as though we had one map, showing government offices and voting districts, but not railways; another map showing railways, theatres and restaurants and phone connection density but not public buildings: both drawn to yield the same detail about major land marks. These maps belong to one family of descriptions of the relations which make up a city from the point of view of a user, for instance, a tourist, or a manipulator, for instance, an urban planner. Because they belong to the same family these descriptions can be superimposed after appropriate scale changes, and they serve as maps in the ordinary sense (maps in tourist guide-books or charts in the municipal planning department).

Other descriptions of R, though they also refer to all R_i in R, do not preserve an originally chosen superordination and subordination ((a) in this case) and thus (unlike (b)) belong to a different family. They reveal the same amount of detail (even the same detail in some cases) but are not superimposable in a display.

In the CASTE example one description of this type takes the "uppermost" topic relation to be a conditional probabilistic model, not probabilistic inference. It would be appropriate if the same topic relations were learned under the title "finite probabilistic automata".

For example (in the city metaphor) a directed graph of the transport network may show as much detail as either of the other maps. But it cannot (in general) be directly superimposed.

To develop these intuitive notions, it is necessary to refine and recapitulate certain technical terms (introduced in Chapter 4) which refer to substructures of topic relations and the role they play in L transactions. It is important to notice that the following definitions refer to an L description of R and not to R itself. Thus the L description, D^1 (R) is an hierarchy or partial ordering of topics; there is a good sense in which within $D^1(R)$ one topic is subordinate or superordinate to others (like the nodes in Plate 3 of Chapter 4). But R itself is a cyclic structure, and it must be, in order that any R_i can be retrieved from other R_j, R_i, in R. Moreover, the entire argument depends upon this fact. The L description $D^1(R)$ deliberately fails to mention most of the linkages that secure cyclicity, but that does not mean that these linkages do not exist.

Subsections 1.7.12.3 onwards chiefly replicate definitions that are given in Chapter 4.

1.7.12.1. The L^1 predicates (L^1 adjectives standing for properties or relations designated by L^1 expressions) are:

(a) Unary (one place) but many-valued predicates called the *descriptors*, sometimes ordered by *integer;* for example, the predicates with values 1, 2, ... and those with values A, B, ... : the predicates with values "real"/"abstract" and "structural model"/"measure". The grain of any description $D^1(R)$ is such that it can be used to pick out, uniquely, each of the nodes that acts as a place holder for a topic relation R_i (where "i" is an external observer's name for R_i, a noun in L^*).

(b) *Marker* predicates, corresponding to the signal lamps positioned at each node in CASTE with values that indicate the state of this node at any occasion: for example, the node is marked as: Understood, an Aim node, a Goal node, a Subgoal node, undergoing Exploration, or a Member or Workset.

(c) The many place predicates, implicit in a graphic display such as the CASTE display, that indicate, in L^1, the connections between nodes that correspond to an external observer's L^* account of relational operators that carry one R_i into another R_j.

(d) It is assumed that a participant can perform mental operations (the <u>Proc</u>^{1} of Chapter 4, Fig. 1 or Fig. 2) imaged by the relational operators; though it is common practice to coalesce all the kinds of relational operator under one rubric of "discovery".

1.7.12.2. The L^0 predicates (L^0 adjectives used to describe what may be done rather than what may be known) are as follows:

(a) Unary but many-valued predicates standing, in L^0, for the values of properties computed by concepts a participant entertains or holds in his cognitive repertoire; the properties specifying the state set, X, computed by primitives (<u>Proc</u>^{0} = <u>Prim</u>^{0}) and identity (also <u>Prim</u>^{0}).

(b) Many place predicates standing (alone or in groups) for the operations $y \in Y$ available at the outset.

(c) For each node i marked understood the respondent can (if he wishes) regard the relation R_i as though it is a property because, if node i is marked understood, by the CASTE facility, then tests have been carried out to determine that <u>Proc</u>^{0}i exists in the learner's repertoire.

(d) Thus the effective L^0 predicates change as learning proceeds. For the experiments described in Chapter 4 we insisted that certain relations were understood and regarded as L^0 properties at the outset, those on the lowest line of Plate 3.

1.7.12.3. Recapitulation. From Fig. 6 of Chapter 4 the L^1 description $D^1(R)$ has both conjunctive and disjunctive substructures. That is, there may be one way of getting to know R_i (conjunctive) or several ways of getting to know R_i (the disjunctive substructure).

For node i (the place holder for topic relation R_i) the nodes subordinate to it by one arc are called <u>Im Ent Set</u> i. (Immediate Set of node i). For example, $\{\beta, \gamma\}$ is <u>Im Ent Set</u> α in Fig. 6a of Chapter 4.

1.7.12.4. If there are several ways of coming to know R_i then there are several sets of subordinate nodes, indexed k, namely <u>Im Ent Set</u> k,i: for example, <u>Im Ent Set</u> 1, d is {b, d} and <u>Im Ent Set</u> 2,d is {c, d} in Fig. 6b of Chapter 4. The union of all <u>Im Ent Set</u> k,i is <u>Im Ent Set</u> i.

1.7.12.5. For any R_i in R trace out ways of getting to know this topic relation by (usually bifurcating) paths emanating from node i. Each distinct class of paths (each way of getting to know R_i) is a completely conjunctive substructure of $D^1(R)$. The set of nodes headed by node i and traced in one of k completely conjunctive ways to a depth of d arcs distance from node i is called a kernel of node i extending to depth d (if no depth is specified, then it is merely one of the kernels of node i and there are k_i of them. k_i is evaluated when some search depth is cited; notably all of the nodes in <u>Im Ent Set</u> k,i are at depth of one arc from node i as in Fig. 8 of Chapter 4).

1.7.12.6. The union of all the kernels of node i is called the <u>Entailment Set</u> of node i (without qualification about how R_i is known, since all of the k distinctions are glossed by union). The entailment set of node i is written <u>Ent Set</u> i.

1.7.12.7. For any $D^1(R)$ there is one or more head node i superordinate to the rest, with subordinates, in <u>Ent Set</u> i. R_{Head} may be unique or not. If not, its member relations are analogous in the sense of Fig. 7 in Chapter 4. This statement is made about $D^1(R)$, not about R. Since R is cyclic there is no unique head node in R itself.

1.7.12.8. Henceforward, these definitions are taken as known, and are used quite freely; L^1 predicates, L^0 predicate (or generally L predicates); <u>Im Ent Set</u> k,i of R_i in $D^1(R)$; <u>Im Ent Set</u> i of R_i in $D^1(R)$; <u>Ent Set</u> i of R_i in $D^1(R)$; Head or R_{Head} of $D^1(R)$.

1.8. *Individuals.* The commentary in Section 1.7 was founded upon an implicit supposition that a pair of individuals, A and B, could be distinguished apart without reference to the conversation in which they are engaged. Though plausible, this supposition cannot be upheld in practice. True, there are many ways of demarcating entities loosely called "individuals" (for example, by head counting) but when the entities are isolated they are not usually found to have the unitary or integral qualities required of A and B.

1.8.1. An external observer, looking on at an L conversation, can resort to many kinds of individuation. Two extreme methods are as follows.

1.8.2. To demarcate a processor, independently of the procedures it is executing. This is "Mechanical Individuation" or M Individuation since it resembles the isolation of a specific general purpose computing machine with a fixed spatio-temporal location.

1.8.3. To demarcate a coherent cognitive organisation or stable class of procedures, independently of the processors in which the procedures are executed. Such entities are called Psychological Individuals or P Individuals.

The most convenient definition proceeds thus:

Any strict conversation on domain R over occasion 0, 1, ... n, n + 1, ... N is a P individual in its own right; moreover, it can be factored into a pair of entities A and B of which at least one (possibly both) are also P Individuals. To be non-committal on this

point, A and B are called participants. One of them (by convention A) is certainly a P Individual in the context of <B, R>. The other may be.

1.8.4. Due to the form of this definition, the P Individual has a certain primacy. Its integrity as a P Individual is due to the fact that the procedures which make it up are self reproducible in the conversational domain R. But they cannot in fact, be reproduced unless they are executed in an M Individual which is an L processor. Hence M Individuation is needed in order to talk about or set up a strict conversation, as well as P Individuation. It happens that P Individuals do not correspond, one to one, with distinct M Individuals unless special precautions are taken and the conversational milieu is specially designed (as it is in CASTE or as it may be in non-mechanical conversations like interviews and tutorials).

1.8.5. The phrase "self-reproducible" is used in the sense of the theory of self-reproducing automata (Appendix F) and it is crucial that a self-reproducing system can be recognised independently of the processor(s) in which it is being executed.

In the case of strict conversations we use an equivalence, proposed by Loefgren, between explanations, modelling operations and reproductive operations, to recognise agreement over the explanation (modelling or reproduction) of a relation and which, if conjoined with evidence for why or how the agreement was reached, signifies an understanding. The recognition of an understanding marks the end of an occasion, during which the strict conversation was a self-reproducing system.

Regarding the processors that execute the procedures in a strict conversation, there are obviously constraints such as "any competent processor must be L processor" as well as more specific limitations upon "compilers" for L procedures and the like. For brevity a P Individual's processor must be compatible with the P Individual. But if there is one compatible processor then there may be indefinitely many compatible (as well as indefinitely many incompatible) processors.

1.8.6. A P Individual is processor-independent insofar as it is immaterial which compatible processor executes the constituent procedures; it is immaterial whether the P Individual is executed in one processor, or several P Individuals are executed in the same processor. In fact, a strict correspondence or even a strong correlation between P Individuals and their processors is seldom manifest and as a rule the P Individual is distributed under execution. Further, a P Individual (unless qualified in some way) has no necessary spatio-temporal location. The P Individual is an execution of program statements in the conversational object language L and shares the quality "lack of a spatio-temporal locus" with any other class of L statements (of course an L statement may refer to time and place; further an utterance of the statement, one particular execution of a Proc, occurs at a specific time and place).

The P Individual is properly specified with respect to a language (L) and a conversational domain (R) in which (whatever else it may be) the P Individual is self-reproducing. Interesting P Individuals do a great deal more than reproduce themselves; for example, they evolve in a conversational domain as a result of mutual understanding and this "evolution" is literally "learning".

Some familiar examples of P Individuals in other fields are as follows: A role in society (realised by any of a class of human beings); A character in a play (realised by any competent actor on a stage); A species (realised by any member organism).

1.8.7. Many sorts of M Individual can be distinguished by the methods of classical physics and behaviourism. Though a human brain is an obvious candidate for M Individuation, the fabric of an M Individual is not necessarily biological. "Mechanical Individual" carried no committment on this issue (the brain for example, counts as a biological mechanism) and it is worth commenting that there is nothing in the specification of a P Individual to indicate that it must be executed by a brain.

Just as a P Individual is specified independently of the processors that execute it, so an M Individual is specified independently of the procedures it may execute (except for limitations which render it incompatible with certain procedures; in this respect it stands in the same relation to a procedure as a general purpose computer augmented by permanently attached compilers, executive routines, etc. to its program).

Some uniformity is added by noting that an M Individual is unitary, integral, and recognisable, for precisely the same reason as a P Individual; namely, it is a self-reproducing system. Only, in this case, the replication processes are biological or contingent upon physical laws (determining the stability of materials) rather than symbol manipulating processes. Since they are independently

identified, M Individuals and P Individuals belong to distinct ontological classes in Harres sense, at any rate[9].

M Individuals differ according to the fabric of which they are made, their capacity for data storage and the arrangements for determining sequences of operations and overall control. All of these could be significant, but for the present purpose, the last type of constraint is of paramount importance i.e. the arrangements for controlling the execution of processes (Appendix H). We shall treat this constraint in terms of processor clocking (the notion introduced in Fig. 1 and Fig. 2 of Section 1.7) and assign one processor clock to determine an execution sequence for each locus of control. These clocks (oscillators driving shift registers if the reader prefers it) act as independent units i.e. each locus of control represents an asynchronous automaton. But depending entirely upon the procedure undergoing execution, the otherwise asynchronous loci of control may become synchronised by virtue of interactions prescribed by the procedures; not by the M Individual (Appendix G and Appendix H).

So, for example, a one clocked M Individual is a serial processor. A many clocked M Individual may accept several non-conflicting procedures and execute them simultaneously but without interaction; that is, "in parallel". On the other hand it may accept a procedure, parts of which can be executed simultaneously, but such that the partial results of one computation constitute initial conditions for another; that is, it may compute "concurrently". The interactions that synchronise otherwise independent automata (the loci of control) constitute

[9] Readers with an exclusive taste for monism may be disquieted by the suggestion of two (and if two, why not more) ontological categories. To reassure them, it is stated, once and for all, that the theory is formulated in respect of an external observer. Hence, the theory is in no essential way effected if the two entities "M Individuals" and "P Individuals" are replaced by the two observation processes, "M Individuation" and "P Individuation". For each occurrence of "M Individual" it is legitimate to substitute "the observer's M Individuation of X" and for each occurrence of "P Individual" to substitute "the observer's P Individuation of X" where X is the conversation under scrutiny. If the argument were written in that way it would, however, be a great deal lengthier. Hence, there is no necessary philosophical committment to one position or the other. For my own part, I feel that a systematic dualism or pluralism is compatible with scientific method in the broad sense, and am inclined to the view that it may lead to a neater picture of reality as well as a more condensed method of exposition.

information transfer; and only such synchronising interactions convey information[10].

1.8.8. The clocking of an M Individual characterises the number of control loci it can accommodate and consequently the types of procedure it can execute (in particular, from the prefactory comments to Section 1.7.1, if a relation is taken as a verb or process then this number specifies its irreducible adicity). More generally, any procedure whatever is placed in register with an M Individual (and thus executed) by establishing correspondence between the order of operations in the procedure and the beats of the processor clock(s). In particular, these comments apply to classes of procedures such as P Individuals.

It will be convenient to distinguish the following categories of M Individual.

(a) L Processors that are compatible with and hence able to execute some specified P Individual in a given domain R.

(b) L Processors able to execute some P Individual but not necessarily compatible with a specific P Individual.

(c) Processors that are not L Processors; which may execute serial (or near serial) procedures but may not execute observable P Individuals.

(d) Storage media structured by "hardware" constraints (in the sense of data organisation, word length, etc.) accommodating serial or parallel computation if driven by one or several external clocks.

Since an observable P Individual is a conversation involving participants A and B (Section 1.8.3) and since A and B are distinct apart from the information transfer due to the conversation, it follows that A and B must have at least two loci of control; so an observable P Individual can only inhabit a many clocked processor. Scrutiny of Appendix F shows that a self-reproducing system is otherwise Turing representable and thus open to serial execution. It follows that any L processor (category (a) or (b)) is

[10] The usage is appropriate and in accord with Holt (1968) or Wattanabe (1963). It does not, of course, correspond to "information transfer" in the technical sense of communication theory (Shannon and Weaver 1949, Gabor (see Cherry, C. 1957) or multivariate information analysis (Ashby 1969, Garner 1962, McGill 1963) where (appropriately in a different context) the term refers to selection that reduces an observers uncertainty or increases the specificity of his estimates.

many clocked, that a two clocked processor is a candidate for inclusion in category (b) but that compatibility (and thus inclusion in category (a)) depends (amongst other things) upon there being sufficient processor clocks to accommodate the control loci required by a P Individual's procedures when executed in a specified conversational domain.

Conversely, a one clocked processor cannot execute an observable P Individual. Although the restriction could have been imposed in other ways, we have specified a modelling facility (Sections 1.7.1, 1.7.4, 1.7.5, 1.7.6) as a processor that is not an L processor because it is rendered one clocked by the trick of stopping and zeroing the execution clock (τ) if the modelling clock (t) is started. This also (and equivalently) establishes the structure/function distinction mooted earlier. Hence, as it stands, category (c) consists in one clock processors but (as later) this limitation is unnecessarily rigid.

Finally, we represent category (d) Individuals (storage media) as processors that have as many asynchronous clocks as they have addressed positions; these clocks execute identity operations (one to each of the addresses) that rewrite the stored data. This image is devoid of any profound connotation; it is chiefly justified by convenience. By picturing storage in this way it is possible to regard the reading and writing operations that inscribe or delete data as synchronising operations and/or to adjoin special clocks that allow us to instrument a recently proven equivalence between software (program) representations and hardware (storage organisation) representations.

1.8.9. The categories (a), (b), (c), (d), of M Individuals feature in the theory as follows. L Processors (category (a) or (b) are putative embodiments of P Individuals, conversations included. For a particular P Individual, in a given domain, an L processor may or may not be compatible (in Category (a)) and thus able to execute it. The issue of competence, Chapter 3 or Pask and Scott (1972) is expressed in terms of the compatibility of a human brain, qua M Individual, with the P Individuals that characterise different classes of learning strategy (serialist and holist). Conversely the issue of strategic compatibility is expressed in terms of compatibility between P Individuals under execution in the same L processor. The phenomenon of cognitive fixity is a special case; the compatibility between a cognitive organisation established by learning about a given conversational domain and a distinct organisation introduced, for example, as an imposed teaching strategy.

Category (c) (processors that are not L Processors) serve as the paradigm modelling facility and have already been discussed; a facility limited to a model class M is simply a one clocked processor inhabited by a procedure which provides the additional constraints required by M.

Category (d) processors typify the interface mechanism of CASTE. Recall that the interface contains a permanent inscription of the L description $D(R) = D^1(R), D^0(R)$ of the conversational domain. During any occasion, the participants A, B have order-independent access to this data and, depending upon their activities, the nodes that stand as place holders for topic relations R_i are marked by signal lamps indicating the values of predicates (aim, goal, understood and so on) that describe the current state of a node. The physical inscription of D(R) together with the node marker values, is called the *entailment structure;* the physical inscription of $D^0(R)$ together with the modelling facility (in this case STATLAB) is called the *task structure;* between them, the entailment structure and the task structure are the interface which is embodied in an M Individual of Category (d). By electing to represent storage in a peculiar (and at first sight outlandish) way it is possible to speak, meaningfully, of synchronising the interface with respect to two processors one of which is the students brain and the other of which is the serial processor for executing the B heuristic detailed in Appendix D and Appendix E. Consequently some of the students procedures (those of a P Individual A) may be executed in the interface and some of the B Procedures may also be executed in the interface; to this extent a conversation, itself a P Individual, is externalised. Stated otherwise, all information transfer due to the concurrent execution of A and B is mediated through the interface.

2. Conversation theory, external observers and participants

A conversation (unqualified) is described by an external observer in a metalanguage L*. Usually, L* is a natural language. The conversation itself takes place in an object language L which could also be part of a natural language (quite conceivably the

same one) but which is described and formalised in L*; either completely or partially.

Regarded as a class, conversations stand out on casual scrutiny but become oddly elusive when efforts are made to give an exact account of them. For example, conversations are not always localised either in time (beginning, ending) or in space. Again, in our culture, there is strong pressure to say that concepts "emerge in" conversation but that a concept "belongs to" one or other participant. As a rule, such remarks are inconsistent. The trouble is only exacerbated by quoting some version of "the whole is (obviously) more than the aggregation of its parts". For example, "concepts arise in the interaction between the participants" merely begs the question of what a participant is. This particular problem is highlighted by noting that if "conversation" and "concept making" are taken to be equisignificant, then many conversations go on in a single brain. For instance, most thinking is a conversation of that type. By the same token, if a human being is said to "learn on his own" surely his brain incorporates a student-like process that learns and a teacher-like process that (at the very least) directs the learner's attention to a different facet of the subject matter.

Turning to strict conversations (as in CASTE), these difficulties are suppressed by a number of tricks, some played in specifying L, the conversational object language, and some played in identifying the participants and recognising occasions upon which they reach mutual understanding.

2.1. *Use of the conversational object language.* L differs from most formal languages in the ways considered in Section 1.7. (it is a command and question language not an assertoric language like the predicate calculus, it is based on L metaphors designating material analogies not on propositions that stand for simple relations that are true or false etc.).

With these distinctions in mind, let us review some assumptions, governing L dialogue, that can be made about L users in order to guarantee understanding.

The required guarantee might be secured by dint of psychological assumptions about mental mechanisms. For example, an L user might be assumed able to execute all of the primitive operations and, before the conversation begins, to understand some of the topic relations. If so, he will either be able to bring about all of the topic relations in R, if commanded to do so (similarly to give explanations of each one, if questioned). Moreover, it might be assumed that the L user is constructed to actually obey commands or actually answer questions.

An alternative, which calls for less commitment, is to notice that if an L user was able to understand some topic relations in R (those in an appropriate group of Im Ent Sets) using an L legal method, then he can come to understand all of the R_i in R, if furnished, on relevant occasions, with the information in D(R). This type of assumption is used in Section 1.3. Though less restrictive than the mechanistic or psychological assumption it relies upon an experimental contract (Section 1.2) by which the L users participating in a strict conversation agree to adopt certain roles (like teacher and student) and to concentrate (exclusively) upon the given interpretation of L.

As it stands a *Role* is a normative constraint expressed in the observer's metalanguage, L* and beyond the compass of L. For example, the role of student involves the idea that some L user has scholarly purposes and actively pursues them. It will be shown that if one participant (B) is specially constructed then the pragmatic issue (A's purposes) may be encompassed by L given only the general caveat that procedures are in fact executed on receipt of the appropriate commands or questions. This leads to an inverse expression of Role. For example, with Role as an extra theoretic (L*) construct, any student is seen to exhibit a learning strategy which, in CASTE, is externalised at the interface. From the other point of view, the Role of student is characterised by the existence of a learning strategy at the interface, and if so (given the caveat that procedures are, in fact, executed) it is legitimate to infer that certain P Individuals (the participants of Section 1.8) will be students.

The reader sensitive to logical niceties will have noted that the CASTE language incorporates these facilities and that all of them were exercised by the students discussed in Chapter 4, though they are glossed by a superficial account (such as Table 1, Chapter 4) of permissible L transaction types. Table 2 (this chapter) summaries the transaction types as they are properly formulated. It is intelligible alone if the reader wishes to take certain implicit dogmas for granted. The arguments that underpin Table 2 are developed in Appendices F and G.

2.2 *Conversational skeleton*. The other tricks (of identification and synchronisation) involve the external observer. They are shaped by the mores and conventions of scientific discourse in the metalanguage L*. The external observer is an external observer (a scientist, not a participant) because he wishes to maintain a numinous and unbiased stance. One way of putting the matter is to say that the conversation (like any other experiment) occupies the observer's attention and is impersonally pronominalised as an it (not a "you" or an "I"). Thus an external observer does not issue commands; he performs parametric operations. Nor does he ask questions; he makes measurements or recordings at the interface. Scientific statements refer to it and are made, in L*, to other scientists; for example, statements which describe the conversation's configuration or condition; that predict occurrences; that prescribe parametric changes; and so on. "External Observer" is a professional role, and the difficulties alluded to earlier are all dependent upon adopting this role; for instance, there are no such "difficulties" in talking about conversations as a participant.

Another way of delineating an external observer's status with respect to the strict conversation he observes is to note that when playing the part of observer he is causally related to the conversation. As used in this context, "causal" is to be contrasted with "derivational" or "dialogue like" or to coin a term "provocative"; not, for example, with "probabilistic". The point is, that statements addressed to "you" (to a person rather than "it") do not, in the ordinary sense, act as causes for effects. For instance, a command does not cause obedience; nor does a question cause an answer. This is a matter of form, and is independent of occurrence ("the question causes him to answer" may be counterfactual as well; i.e. the question may actually give rise to another question; but that is beside the point). As a participant, I am at liberty to regard you (another participant) from several points of view. On the one hand I can address you by name and ask you a question, in which case casuality is inapplicable. Equally, uttering the same words, I can regard the question event as a stimulus which (if effective) is certainly one cause of your answer, regarded as a response.

An external observer does not have this much freedom. He must regard the strict conversation, or any part of it, impersonally. What he does to this system is either ineffective or something that causes an effect. In particular, parametric inputs from the external observer cause changes in the conversation.

It is immaterial whether the causality is deterministic or not. If the observer has a detailed hypothesis about how the system works he may deduce the effect of his causative actions. In partial ignorance of the system he relies only upon inductive inference when predicting an effect or hypothesising what caused an effect.

2.2.1. *Causal and provocative coupling of participants.* Since the distinction between causal and provocational linkage is used widely in the sequel, it is given a special notation, shown in Fig. 3. Any distinct entity (for example, one of the participants, or a particular concept Proc i) is enclosed in a box. In Fig. 3 (I) a^1 acts causally upon a^0 through a cycle involving an operation (parametric arrow) and a description (the shaded comparator symbol). The meaning of Fig. 3 (I) is that a^1 regards a^0 as an it about which a^1 has a deductive or inductive hypothesis and the expectation that this hypothesis will be confirmed after the operations are carried out (i.e. the description received will tally with the hypothesis). In the deductive case, only denial will inform a^1 since confirmation is anticipated.

Any other cyclic linkage is provocative and is a search expected to furnish or to generate information. The simplest provocative linkage is shown in Fig. 3 (II) but such cycles may bifurcate and rejoin, as in Fig. 3 (III) and may also be combined (over the same set of boxes) with causal linkages (Fig. 3, IV). The meaning of an entire (possibly complex) cycle is the demand for and the production of an explanation (or a class of them). Breaking the cycle at any one point (for example, the output of a^1) the transaction may be interpreted, on the one hand, as "Issuing a command" or "Posing a question (requiring an explanatory answer)" or "Presenting a choice amongst alternatives" (a question requiring a selection as an answer); on the other hand as "accepting a command in order to obey it" or "essaying an explanation" or "deciding". Notice, however, that acts like "executing a command", "building a model", "giving an explanation" or "selecting a reply" involve causal transactions i.e., the doing agent has a hypothesis that whatever is done will, or is likely to, achieve the desired result.

The figures (from Fig. 1 to Fig. 3, and Figs. 4–6 to be introduced) are not merely system flow charts, though they

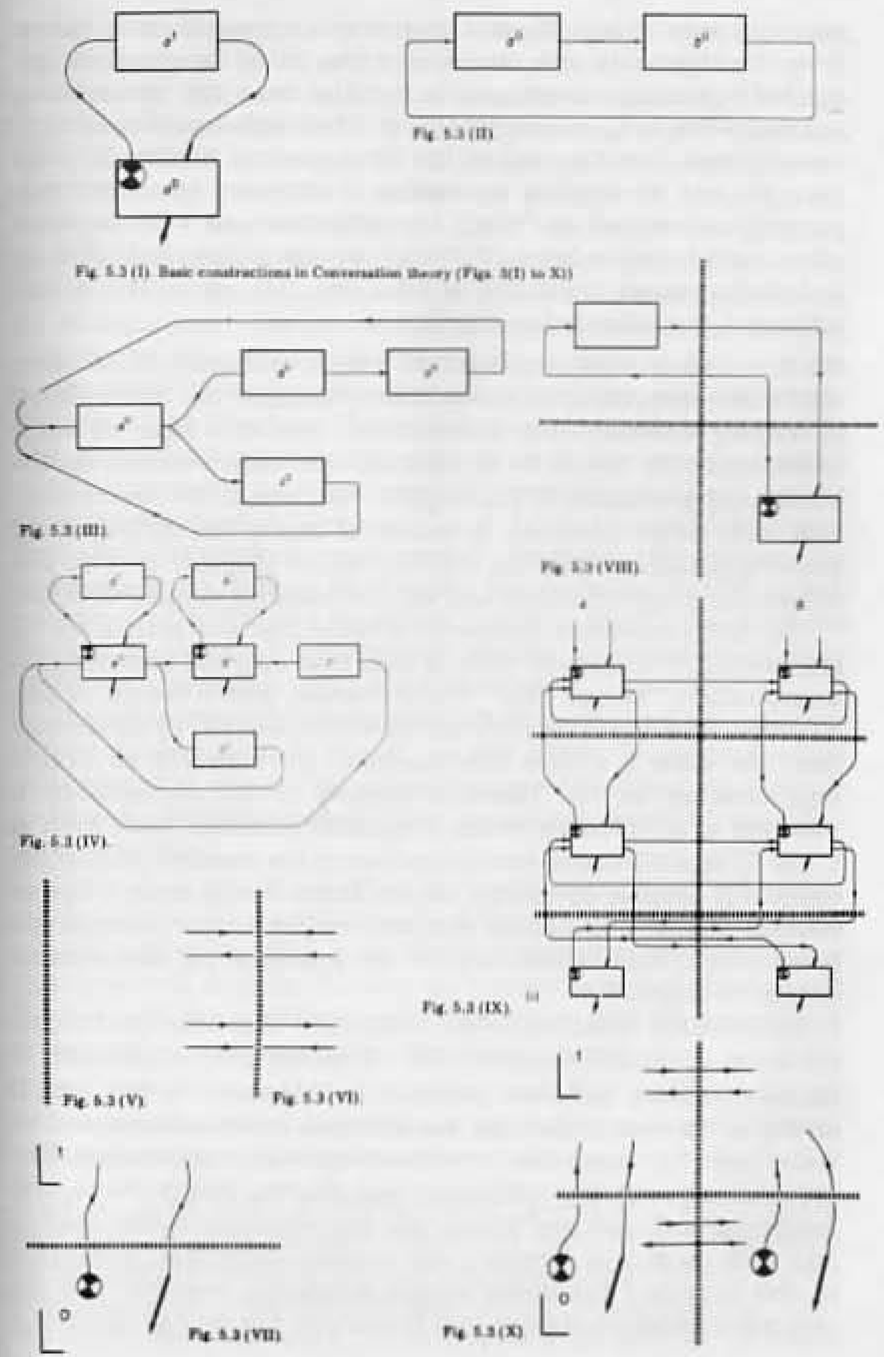


Fig. 5.3 (I) Basic constructions in Conversation theory (Figs. 3(I) to X))

resemble such things. Certain very definite consequences follow from drawing them and, throughout the paper these and similar spirited constructions are used to build up icons that are used like equations (in fact, as expressions in L* describing permissible L transactions). Development of the icons starts in Section 2.5. For example, any provocative transaction is addressed by some entity properly referenced as "him" (or self-referenced "I") to some other entity (self-referenced "you" by the originator). Just as definitely, causal transactions refer to "It" and "It" is not addressed, but ostended or attended to.

2.2.2. *Conventions employed to resolve ambiguity.* Two other scientific conventions, of lower calibre, underlie the tricks played in tidying untrammelled conversation into the form of strict conversation. It should be emphasised that these conventions are introduced as a matter of convenience (as props to L* communication with other scientists, as means of easing calculation, or of avoiding paradox within the scientific axiom scheme); they do not reflect the nature of reality and are not (usually) claimed to do so.

The first convention represents a belief that any system can be regarded as *it* or *causally* with no loss. If an external observer calls a respondent "he" or "she" it is a courtesy and is devoid of any scientific meaning. This point of view is burlesqued by statements like "the world is a finite state machine" (perhaps with an infinite tape attached to it). Taken in context, if the conversation is observed at an interface which is spatially localised (both given in CASTE) then someone who subscribes to the standard contention believes it possible to display all significant events along a line of rational numbers, identified with the reading on one personal and linear clock, that is attached to the interface i.e. the external observer's stopwatch.

Unofficially, most observers conjecture that this bit of conventional wisdom is unsound; but, nevertheless, it is provident, so far as recording and data analysis is concerned, to pay special attention to events that can be depicted in this manner and to foster them by appropriate restrictions upon the conversation. The looked for events are contiguous and discrete events which have beginnings and ends and which may be spaced out in line, head to tail, with no gaps in between. An occasion indexed n, is an event of this type and the understanding condition, together with the regulating heuristic, ensures that it must be. For each occasion it is

possible to determine a unique duration in stopwatch time; durations can be added over a conversation, and so on.

It may or may not be possible to make the same kind of sense out of all observable events, for example, stages in an explanation or a modelling operation. If the events in a conversation were synchronously clocked, it would be possible. But, as a rule, conversations are not synchronously clocked or usefully represented as though they were. Moreover, the special precautions that could be employed to enforce synchronicity disturb the flux of dialogue and, if taken too far, disrupt it. Hence, the external observer is wise to minimise his demands and to insist upon the convenience of stopwatch restricted events over at most a small portion of the interface. This small portion is an entity which even the participants must regard only as an it (i.e. regard causally) which is given the technical name of "modelling facility", and the meaning described in Sections 1.7.1, 1.7.3, 1.7.4 and 1.7.5. Notice that the participants may regard anything (themselves, for instance) as an it; they must regard the modelling facility in this manner. In CASTE, the modelling facility is STATLAB (given the domain of elementary probability theory; a particular modelling facility is appropriate to a particular domain).

The other scientific convention is that mention of self-reference should be avoided. A caveat to this effect is prudent, since self-referential entities are prone to engender vicious cyclicity or unlimited regression when they are manipulated by standard transformations.

There is no serious dispute over the existence of self-referential entities; with rare exceptions all of the entities in a conversation are self-referential. But in a strict conversation, anchored on a conversational domain, R, they are treated as though this was not the case and the appearance of self-reference (not the fact of it) is suppressed by imposing restrictions upon L usage.

2.2.3. *Self-reference.* Two distinct varieties of self-reference exist in a conversation and different injunctions are used to inhibit their appearance at the interface.

2.2.3.1. One kind of self-reference is due to "directing the attention". Begging the open question of what the participants are (apart from the fact that they can issue commands; ask and answer questions) any "attention directing" action on the part of A (say) can be rephrased either as "A commanding himself" or "A asking himself a question". This circumstance is prohibited by the following expedients.

(a) The participants are distinguished as A and B in a canonical fashion so contrived that any self-explanation of a relation R_i in R, on the part of A can be dissected into a command issued or a question asked (by B of A) eliciting in reply either a modelling operation or an explanation, perhaps after several cycles of dialogue. Vice versa, any self-explanation of a relation R_i in R on the part of B can be dissected into commands and questions from A to B.

(b) A and B are prohibited from commanding or questioning themselves directly; if A "changes his attention", for example, he must do so through transactions that lead B to issue the appropriate command. Because of this, Table 2 does not include reflexive commands of the kind $\underline{\text{Comm}}_{AA}$ or $\underline{\text{Comm}}_{BB}$ interpreted as A telling himself to do something and B telling himself to do something. A single subscript is sufficient and is used to designate the addressee. Thus $\underline{\text{Comm}}_A$ is a command addressed to A and $\underline{\text{Comm}}_B$ to B; $\underline{\text{Comm}}_A$ is issued by B and $\underline{\text{Comm}}_B$ by A. Precisely the same comments apply to questions. More generally, by dint of these constraints, all modelling/explanation cycles in a strict conversation pass through a vertical cleft which distinguishes A and B.

(c) This vertical cleft is denoted by "⦙" (Fig. 3V).

(d) The rule is that all connections penetrating "⦙" alone are of provocative form as in Fig. 3 (VI).

(e) Equisignificantly, any transaction that crosses the vertical cleft is personally pronominalised as a command or a question (to you, or A or B) and any response or reply is tagged by its source (his or B's or A's).

(f) A causal transaction is deductively based and refers to *it*. In other words, the responsible participant (A, for example) entertains a hypothesis about how to model a relation R_i which he can instantiate and verify or deny, within the bounds of a modelling facility (Section 1.7), in a universe of his own choice, by forming a model M_A i. Two principal meanings can be ascribed to "A has a hypothesis"; namely, "A has a $\underline{\text{Proc}}_A$ k,i yielding M_A k,i and $\underline{\text{Proc}}_A$ l,i believed to yield M_A l,i = M_A k,i (the hypothesis that $\underline{\text{Proc}}_A$ l,i is a concept for R_i is denied if M_A l,i = M_A k,i is false)" or "A is given the name of R_i; he produces (on command, $\underline{\text{Comm}}_A$ i) the model M_A i, and this model either does or does not match a standard model M_i^*, inscribed in D(R)". The paradigm might have been phrased, alternatively, in terms of an L explanation or an L reproduction of R_i, using the correspondences established in Section 1.7. For a tutorial conversation, correctness (a somewhat weaker criterion) may replace equivalence.

(g) A provocative transaction is an explanation by A to B, or alternatively a model submitted by A for B's scrutiny (or vice versa). Since A's universe of modelling may be distinct from B's it follows (as detailed in Section 1.7) that the confirmation/denial obtained in the causal case according to whether or not M_A i = M_i^*, is replaced by (at most) a criterion of A and B agreement; M_A i ⇔ M_B i (for M_A i submitted by A and M_B i the model, perhaps M_i^* submitted by B). In general M_A i ⇔ M_B i does not imply that A's extension of R_i is the same as B's extension of R_i.

(h) Tests for the linguistic condition understanding are carried out by examining cycles of explanation severed by the vertical cleft symbol "⦙".

2.2.3.2. The other kind of self-reference is obtrusive in connection with procedures, per se. The learning model sketched in Chapter 2 Section 5, is liable to produce procedures (programmes) that "write themselves". There is a sense in which all stable procedures do so, and any discussion of them is beset by well known ambiguities. To avoid ambiguity the external observer imposes a separation of domains. For example, a concept, $\underline{\text{Proc}}$ i, is a procedure operating upon a domain of relations R_i; a memory is a procedure (perhaps the same procedure) operating upon a domain of concepts. The concept and the memory are tagged according to their domain and thus kept distinct.

(a) A horizontal cleft symbol "⦙⦙⦙" indicates the distinction of domains.

(b) The distinction is due entirely to the external observer. There is no reason to suppose that cognitive systems really are hierarchical; it is simply convenient to describe them as though they are.

(c) The rule is that a horizontal cleft "⦙⦙⦙" is penetrated by causal cycles only, as in Fig. 3 (VII). Equisignificantly, these are transactions exclusively concerned with "it". Quite possibly, A may regard a procedure in his own repertoire embodied in an M Individual as "it" (and operate upon it). Or A may regard an environment like the modelling facility as "it" or he may regard B embodied in an M Individual as an environment in which case the outgoing connections penetrate "⦀" first and later "≡" also.

(d) The ruling is that for each participant A, and B there is at least one distinction of the type " "; that for this pair of levels L^r, L^{r+1} (by convention written L^0, L^1 though "0" and "1" have no more significance than "r" and "r+1") there is at least one causal connection and that any causal connection at this level crosses no other boundary. For example, Fig. 3 (VIII) is a forbidden construction. Fig. 3 (IX) is not forbidden (and is interpreted as a causal linkage to an "it" other than "me") since elsewhere in the same construction there is (at least) one level at which the only caveat of Section 2.2.3.1 (d) is satisfied[11]. For example, on each side of "≡" (in A or in B) a *memory* is a Proc acting causally on a domain of *concepts* (alias Procs) to rewrite or construct them.

(e) In any L conversation A and B are brought into proximity at the "≡" cleft with at least one "⦀" cleft in register. Hence, the provocative L transactions penetrating "≡" are stratified and L is said to have levels (of control or organisation) designated $L = L^1$, L^0. For example, A's L^0 description of an environment, in terms of predicates of A's selection, is at a "higher level" than the environment to which the description refers; A's L^1 description of A's concepts (any one of which contains one of A's L^0 descriptions) is at "higher level" than the concept itself.

Equisignificantly, "≡" represents a boundary between two initially asynchronous systems A, B, that become synchronised because information is transferred (in the sense of Section 1.8.8) by the A, B, dialogue (vice versa, the dialogue is due to synchronisation).

(f) Because of that, it is meaningful and necessary to index transactions and procedures by a level-denoting superscript and by a participant-denoting subscript. So, for example, there are Proc_A^1, and Proc_A^0, Proc_B^1, Proc_B^0, the same notation being applied to questions, commands, and descriptions.

(g) Combining the distinctions "≡" and "⦀", together with

[11] Several alternative connections yield the same essential constraint. For example, it is possible to introduce a minimal stratification L^2, L^1, L^0. Similarly it is possible to distinguish the environment external to a participant (that is, the environment in which this participant's procedures are not executed), as distinct from the environment constituting the participant's own processor. These alternatives are just as acceptable, but in practice, the convention selected is the most transparent.

the connection forms they permit, yields the icon of Fig. 3 (X). It is called the conversational tableau, and is the least specific framework in which a strict conversation can be observed over just one occasion.

(h) The conversational domain R (that is, the topic of conversation) is accessible as an "it" to either participant. Since L is stratified ($L = L^1, L^0$) there are two descriptions of R (namely $D^1(R)$, $D^0(R)$ of section 1.2 and CASTE in Chapter 4, Fig. 6) indicating what may be done and what may be known, respectively.

(i) Hence $D(R) = \langle D^1(R), D^0(R) \rangle$ is accessible at the proper level to A or to B. The cleavage planes needed to provide place holders for D(R) (corresponding to the place holders for the Proc s of A and of B) are added to the tableau (Fig. 3 (X)) to yield a conversational skeleton (Fig. 4). This is the least specific structure in which it is possible to observe a conversation (anchored on domain R) over a series of occasions.

To emphasise this point, the external observer's recording equipment is shown attached to the central cleft of the conversational skeleton.

The central cleft is a locus of understanding (involving at least two, usually more than two, loci of control). Hence, this is a locus (in the sense of a confluence of organisations) where the external observer can test for the condition of understanding and determine, thereby, the end of an occasion. Without further qualification, which is given in due course, the locus does not have a well defined spatio-temporal position.

From clause (e) the locus of understanding is also a barrier marked out by the vertical cleft "≡" across which information is transferred between two otherwise asynchronous systems A, B, (each structured by the "⦀" cleft) so that A, B, become synchronised in conversation. Using "information transfer" in this sense (Section 1.7 and Section 1.8.8) it can also be argued that the conversation is due to a complete or partial synchronisation of A and B.

(j) Since the distinction of participants and the distinction of levels are introduced at the discretion of an external observer, there is no objection to adding more distinctions like them. The number is a matter of convenience. Parsimony alone dictates as few inscriptions as possible.

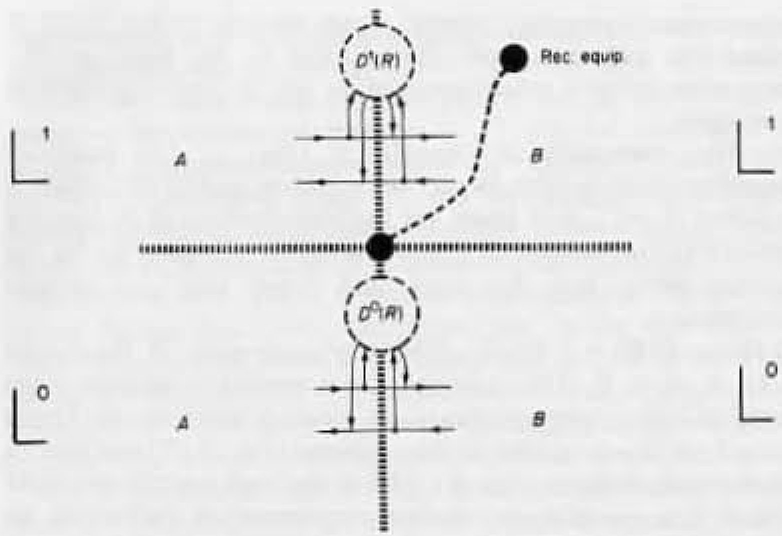


Fig. 5.4. Conversational skeleton.

2.3. *Properties of the conversational skeleton.* Each place holder in the conversational skeleton (each quadrant in Fig. 4) can be filled either by a procedure, Proc i or a nameable collection of procedures and the special circular loci reserved for descriptions, can be filled by task structures ($D^0(R)$ of Section 2.1.2) and entailment structures ($D^1(R)$ of Section 2.1.2) for any conversational domain that is the context in which these procedures may be executed.

Some forbidden or trivial constructions are shown in Fig. 5. For example, Fig. 5 (I) and 5 (II) are unobservable because the asserted distinction between causal and provocative transactions is obliterated. In Fig. 5 (III) it is impossible to impose an unambiguous cleft. Since causal and provocative transactions are confused, the one cleft possible might either be "≡" or "⦀".

The construction in Fig. 5 (IV) is possible but formally disallowed as it eliminates the distinction between L^1 and L^0 where "1" and 0" are merely different indices, r and s regardless of any ordering such as "$r > s$". In contrast, Fig. 5 (V) is permissable on these grounds (for L^r, $L^s = 0, 1, \ldots$. it is true

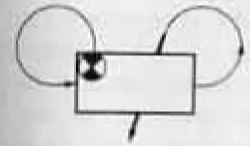


Fig. 5.5 (I) to (VI).
prohibited and trivial constructions that are disallowed.

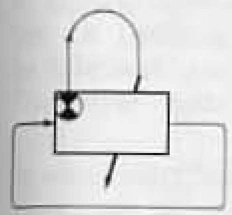


Fig. 5.5 (II).

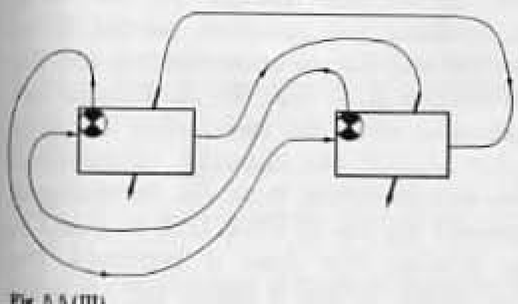


Fig. 5.5 (III).

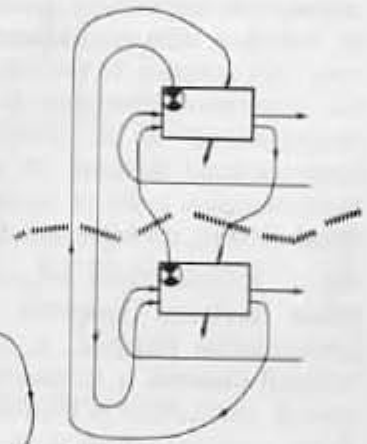


Fig. 5.5 (IV).

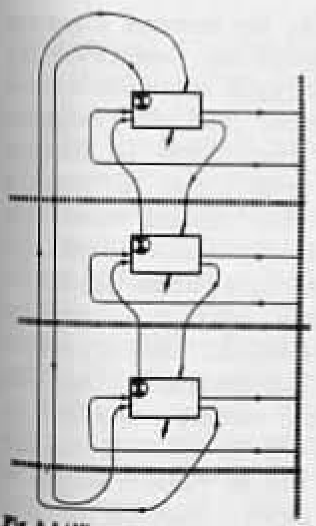


Fig. 5.5 (V).

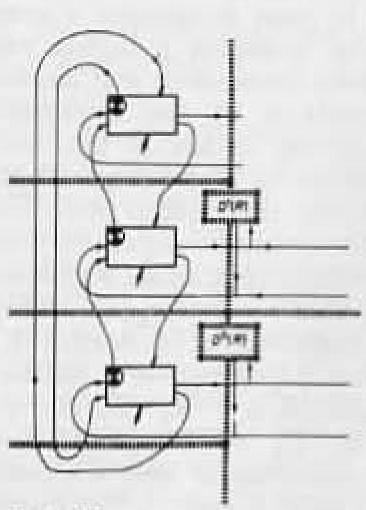


Fig. 5.5 (VI).

that $L^r \neq L^s$) and the intransitivity is generally acceptable, i.e. ($L^2 > L^1$ and $L^1 > L^0$ do not necessarily imply $L^2 > L^0$). But a system of this kind, though it is held to exist, cannot be completely observed since it is impossible to sever all of the transactions between the subsystem (representing participant A) at an interface with participant B, involving just one distinction of level. An instance of the difficulty is shown in Fig. 5 (VI) where the uppermost procedure box is devoid of a specific domain if approximated to an interface of the type specified in the conversational skeleton. However, such systems are observable at more complex types of interface and, unlike the other "defective" constructions, do enter into the scheme of icons.

2.4. *Minimal form of conversational skeleton.* The conversational skeleton specified in Section 2.2.3.2 is the most parsimonious possible. It contains the structure needed if an external observer is to describe and discuss understanding and the general conduct of a conversation given that the participants are stable cognitive organisations and under the assumption that they furnish explanations in $L = L^1, L^0$ (as linguistic expressions) rather than building models and describing them. So, for example, the skeleton does not represent the use of STATLAB in CASTE, or any other modelling facility. Nor does it represent the reproductive processes that render A and B stable and (at least one) a P Individual.

In order to represent a modelling facility the external observer must introduce a further level of stratification, penetrated by causal connections that traverse $\underline{\text{Proc}}^0_A$ or $\underline{\text{Proc}}^0_B$ in the lowermost quadrants of the conversational skeleton. The L^0 dialogue coupling A and B thus includes L^0 descriptions of models themselves and of operations that act upon them. No further axioms are required since, according to the existing rules, any causal input must emanate from a description symbol "Ⓓ" and the corresponding causal output must terminate on a parametric arrow symbol " ⸙ ". Since the descriptions refer to a facility constrained, as in Section 1.7, to accommodate only a certain class, M, of models, it follows that A's description is X_A and B's description is X_B. Further A's parametric output is a selection from Y_A and B's a selection from Y_B. Fig. 6, which shows the construction at issue is a neater form of Fig. 5, VI. It is tempting to assign a level "L^{-1}" to the modelling facility. But this much is

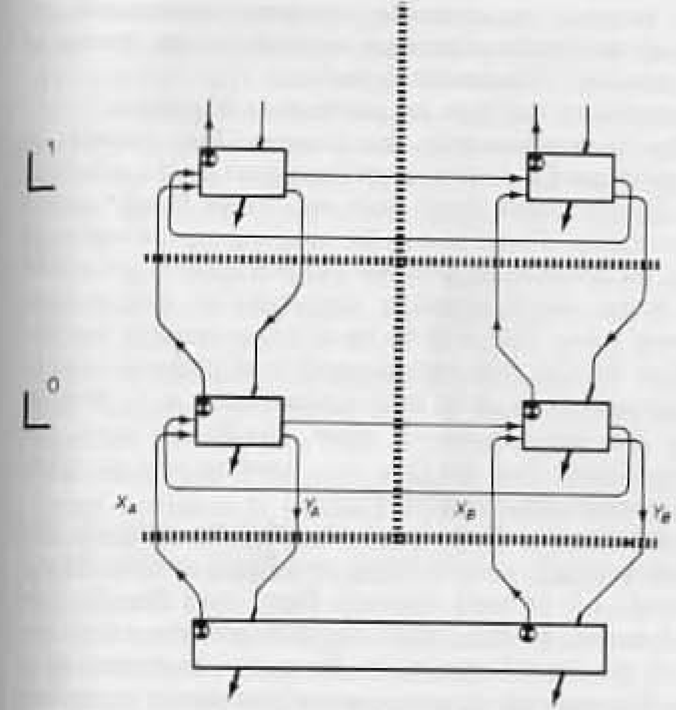


Fig. 5.6. Incorporation of a modelling facility used by both participants.

deliberately not given by the rules. These simply state that any model built in the facility has a level distinct from L^0. It could, for example, be at level L^1, just as well as "L^{-1}".

The construction which makes an L^0 causal input a description of something at level L^1 and makes an L^0 causal output operate upon something at level L^1 is quite legitimate and in case the "somethings" described and operated upon are procedures ($\underline{\text{Proc}}^1_A$) located in the upper left quadrant of the conversational skeleton it means that some procedure $\underline{\text{Proc}}^0_A$ is able to reproduce some procedure $\underline{\text{Proc}}^1_A$; that is, to model it. If such a process took place for all procedures designated $\underline{\text{Proc}}^1_A$ and if (referring to their input and output) they reproduced all procedures designated $\underline{\text{Proc}}^0_A$ then the resulting cognitive organisation would be stable. Though legitimate, we exclude this particular construction as unobservable in a strict conversation (it demolishes the hierarchy L^1, L^0; $1 > 0$ or L^r, L^s; $r > s$ which is needed within the conversational skeleton in order to recognise understanding). However, very similar constructions are employed in the theory to obtain the same result in an observable fashion.

Two constructions of this type are particularly important.

(a) Since the hierarchy within the conversational skeleton is peculiar to a participant A or B it is not destroyed by the coupling which makes $\underline{Proc}_A^0$ model $\underline{Proc}_B^1$ and vice versa $\underline{Proc}_B^0$ model $\underline{Proc}_A^1$. The specificity of level lost in the coupling can be retrieved by recourse to the distinction between the participants, provided that A and B are stable cognitive organisations that remain recognisable over time. This will be true if the coupling has the effect mooted in the last paragraph (namely that all procedures in all of the boxes reproduce all of their subordinates; as in Section 2.5). Notably the satisfaction of these conditions does not preclude the possibility that the Proc s in question may do other things as well as reproducing existing Proc s.

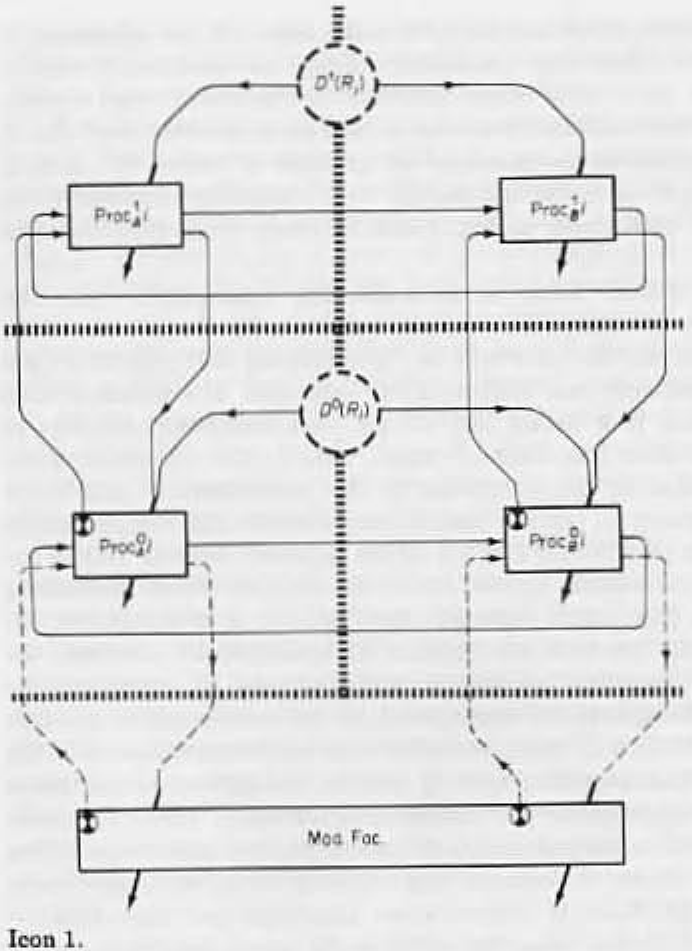
(b) In construction (a) there is no objection to assigning the coupling whereby $\underline{Proc}_A^0$ models $\underline{Proc}_B^1$ and $\underline{Proc}_B^0$ models $\underline{Proc}_A^1$ to a higher level, L^2 (a level "above" $\underline{Proc}_A^1$ and $\underline{Proc}_B^1$). The aptness or otherwise of this usage depends entirely upon the embodiment of the procedures under discussion; their execution in a processor. For example, it seems natural to regard a modelling facility as belonging to a level "lower" than L^0 because STATLAB and its kin are tangible devices. By the same token it seems natural that the same interactions belong to a "higher" level if they constitute A's attempts to model B, or, vice versa, B's attempts to model A. Here participant A operates upon whatever L processor executes participant B and conversely B operates upon whatever L processor executes A (recall, from Section 1.8.8 that any modelling facility like STATLAB regarded as an M Individual, is a processor but is not an L processor). From the present point of view, either "higher or lower" is equally valid. How natural the usage is depends upon the M Individuation of participants, of modelling facilities and the like, in particular kinds of fabric.

2.5. *Concepts and memories: reproduction, construction, and understanding.* Throughout this section it will be assumed that the procedures of a strict conversation can be executed in compatible and appropriately chosen M Individuals. The question of furnishing these M Individuals is taken up in Section 2.6. The current assumption (that the procedures of a conversation can be

and are executed) is necessary to make sense of the argument; it also implies that any procedure (Proc) is associated with a compatible (and thus many clocked) L Processor: that entities D(R) may be inscribed or stored as data at an interface and that if a Proc happens to be executed to produce a model M i then it operates upon a modelling facility with clocking constraints no more tight than those in Fig. 1 and no more loose than those in Fig. 2.

At the outset there is a temporary supposition that the conversation is considered over one occasion, n, which is not made notationally explicit (it could be, by suffixing all Procs by n) and that one and only one relation R_i is ostended. The notation used for ostension is a filling out of the conversational skeleton to produce an icon (the first of these, Icon 1) for representing the condition that R_i is understood by the participants A and B. To image ostension R_i (rather than R) is entered in the compartments reserved for $D^1(R)$ and $D^0(R)$, an arc is drawn from $D^0(R)$ to the parametric or causal inputs of A and B (the boxes containing $\underline{Proc}_A^0$ i and $\underline{Proc}_B^0$ i) to represent the "A! attend to R_i" or the "B! attend to R_i" part of a command or question. In contrast, the provocative coupling between A and B at level L^0 represents the problem solving activity engendered by the command or question in respect of R_i and this provocative transaction takes place in the context of data regarding how R_i may be brought about (shown as arcs at the appropriate level entering or leaving $D^0(R_i)$). The same convention is employed to depict ostension for transactions taking place at L^1 (here, the connections enter or leave the compartment filled by $D^1(R_i)$). If there is no subscript (so that $D(R) = (D^1 \langle (R), D^0(R) \rangle)$ then the participants are at liberty to ostend any topic relation in R_i apart from constraints that appear in other places.

Icon 1 also represents a modelling facility which may be connected to the participants in the manner of Fig. 6. However, the connections are shown as thin dotted lines since they are optional. The optionality is due to the fact that all of the conditions under discussion at level L^0 can be realised by question/explanation transactions only. If a model is made, its construction is interpreted as a practical explanation; for generality, the argument is phrased as though a modelling operation is always required and if that is actually the case then the connections to the modelling facility must be established.



Icon 1.

With this preamble, we shall fill the conversational skeleton to depict agreement over and holding of a concept of R_i; agreement and possession of a memory of R_i; the condition of understanding; the same in respect of a conversational domain; the process of learning and a characterisation of P Individuals. These developments underpin the operation of the CET heuristic (Appendix D and Appendix E) and also lend substance to the rudimentary learning theory outlined in Chapter 2, Section 5.

2.5.1. A concept of topic relation R_i in a P Individual A is a class of procedures $\underline{Proc}^0_A$ i that reproduces R_i as it is known by A (namely as a particular description $D^0_A(R_i)$. Thus:

2.5.1.1. $\underline{Proc}^0_A i(R_i) = <\alpha^0, \beta^0, \ldots . R_i> = D^0_A(R_i)$ where α^0, β^0, are L^0 expressions, the first being axioms in L^0; all of them expressed by $D^0(R_i)$.

$\underline{Proc}^0_A i(X) = <a^0, b^0, \ldots . M_A i> = \underline{Exec}^0_A i$ where a^0, b^0, are partial models at instants t in modelling $X_t = \{x\}_t$. Further, $\underline{Proc}^0_A i(M_A i) = M_A i$ and $D^0_A(R_i) \Rightarrow M_A i$ (if the modelling facility is restricted in the manner of Fig. 1) or $D^0_A(R_i) \Rightarrow \{M_A i\}$ if not.

2.5.1.2. A specific or qualified concept (A's lth concept of R_i) is a serial procedure $\underline{Proc}^0_A$ l,i in $\underline{Proc}^0_A$ i.

2.5.1.3. The execution of $\underline{Proc}^0_A$ i is interpreted (Appendix H) as the execution of any or all of the $\underline{Proc}^0_A$ i; if several elementary procedures are executed then the execution is concurrent; the unqualified execution of $\underline{Proc}^0_A$ i is interpreted straightforwardly as the concurrent execution of all procedures or of the concept as a whole. This yields $D^0_A(R_i)$. If the modelling facility were an L processor (it is *not*, by edict) then $D^0_A(R_i) \equiv \{M_A i\}$. Due to modelling facility restrictions only some (perhaps one) $M_A i$ is actually built.

2.5.2. Suppose that distinct participants A and B ostend R_i at occasion n and that they agree about their concept of R_i. That is $D^0_A(R_i) \Leftrightarrow D^0_B(R_i)$ and if a model is actually built $M_A i \Leftrightarrow M_B i$.

Agreement over a topic relation R_i is pictured (Icon 1) by ostension and the provocative coupling that joins $\underline{Proc}^0_A$ i to $\underline{Proc}^0_B$ i at level L^0. Model building is optional.

2.5.2.1. The coupling is secured by a vertical cleft. Consequently it can be represented by a command and question transaction between the participants, using the command and question forms in Table 2. The symbol "$\circ\!\!\rightarrow$" denoted "provokes in the addressee" and the transactions will be expressed one sidedly, in terms of commands/questions addressed by B to A which elicit responses/replies from A to B.

We express the transactions leading to an understanding by slightly complicating the commands and questions (notably the *Base* commands) introduced in Section 1.7.7 and Section 1.7.8. Eventually, these are referred to the CASTE transactions of Chapter 4.

2.5.2.2. The base command and the unqualified question form is as follows.

TABLE 5.2
Command and Question Forms of L Transaction needed for a strict conversation on a conversational domain R with topic relations R_i in R. Those transactions that are not directly observable because they correspond to models in an L processor (not in a modelling facility) are circled in the Table. But each "unobservable" transaction is imaged by a "fully observable" stretch of L dialogue ($\underline{Expl}^1$ i or $\underline{Expl}^1$ ji).

		Commands	Questions	Executions	Explanations
L^1	Base	$\underline{Comm}_A^1$ i	$\underline{EQuest}_A^1$ i	$\underline{Exec}_A^1$ i	$\underline{Expl}_A^1$ i
		$\underline{Comm}_B^1$ i	$\underline{EQuest}_B^1$ i	$\underline{Exec}_B^1$ i	$\underline{Expl}_B^1$ i
	Qualified	$\underline{Comm}_A^1$ ji	$\underline{EQuest}_B^1$ ji	$\underline{Exec}_A^1$ ji	$\underline{Expl}_A^1$ ji
		$\underline{Comm}_B^1$ ji	$\underline{EQuest}_B^1$ ji	$\underline{Exec}_B^1$ ji	$\underline{Expl}_B^1$ ji
L^0	Base	$\underline{Comm}_A^0$ i	$\underline{EQuest}_A^0$ i	$\underline{Exec}_A^0$ i	$\underline{Expl}_A^0$ i
		$\underline{Comm}_B^0$ i	$\underline{EQuest}_B^0$ i	$\underline{Exec}_B^0$ i	$\underline{Expl}_B^0$ i
	Qualified	$\underline{Comm}_A^0$ ji	$\underline{EQuest}_A^0$ ji	$\underline{Exec}_A^0$ ji	$\underline{Expl}_A^0$ ji
		$\underline{Comm}_B^0$ ji	$\underline{EQuest}_B^0$ ji	$\underline{Exec}_B^0$ ji	$\underline{Expl}_B^0$ ji

$\underline{Comm}_A^0$ i = <A! R_i/$\underline{Precon}^0$ i> $\circ\!\!\rightarrow$ $\underline{Proc}_A^0$ i (X) = $\underline{Exec}_A^0$ i Where $\underline{Precon}^0$ i is the modelling facility.

$\underline{EQuest}_A^0$ i = <A? $\underline{Expl}^0/R_i$> $\circ\!\!\rightarrow$ $\underline{Proc}_A^0$ i (R_i) = $D_A^0(R_i)$ = $\underline{Expl}_A^0$ i where the precondition is the statement of R_i in $D^0(R_i)$. If the modelling is unrestricted $\underline{Expl}_A^0$ i ≡ $\underline{Exec}_A^0$ i (Appendix F) and the terminal model is M_A i.

2.5.2.3. The qualified command and question forms are $\underline{Comm}_A^0$ l,i = < A! R_i/Precon^0 i ∧ $\underline{Stat}$ l > $\circ\!\!\rightarrow$ $\underline{Proc}_A^0$ i (X) = $\underline{Exec}_A^0$ l,i in which the terminal model is M_A l,i.

$\underline{EQuest}_A^0$ l,i = < A? Expl^0 l/R_i> $\circ\!\!\rightarrow$ $\underline{Proc}_A^0$ l,i (R_i) = $\underline{Expl}_A^0$ l,i. where $\underline{Exec}_A^0$ l,i = D^0 ($\underline{Expl}_A^0$ l,i) (the execution is serial).

2.5.2.4. Rewriting these expressions as commands or questions that are addressed by A to B and noting (initial supposition) that A and B agree (so that $D_A^0(R_i) \Leftrightarrow D_B^0(R_i)$) yields a symmetrical system, which is the L^0 coupling in Icon 1.

2.5.2.5. In general (as in Chapter 2, Section 5) reproduction is designated $\underline{Rep}$ so that

$\underline{Concept}_A$ i $\triangleq$ $\underline{Rep}_A$ (R_i)

or preserving level

$\underline{Concept}_A^0$ i $\triangleq$ $\underline{Rep}_A^0$ (R_i)

2.5.3. A *memory* of topic relation R_i, in a P Individual A is a class of procedures that reproduces some or all of A's *concept* of R_i namely $\underline{Proc}_A^1$ i. Since the execution of $\underline{Proc}_A^1$ i takes place in an L processor that also embodies $\underline{Proc}_A^0$ i (not in a modelling facility) the stages in the concurrent execution series are not necessarily ordered. However, in conformity with the previously established notation they are represented as though they were (keeping the fiction in mind).

2.5.3.1. The result of execution is a dynamic model in an L processor, thus a replica of $\underline{Proc}_A^0$ i executed by this L processor.

$\underline{Proc}_A^1$ i (Proc_A^0 i) = <a^1, b^1, ... $\underline{Proc}_A^0$ i> = $\underline{Exec}_A^1$ i ≡ $D_A^1(R_i)$. Where $D_A^1(R_i)$ is A's explanation of how he constructed the procedures in $\underline{Proc}_A^0$ i.

2.5.3.2. A general memory may be qualified (that is, A can usually reconstruct $\underline{Proc}_A^0$ i by several methods). The kth method is $\underline{Proc}_A^1$ k,i ($\underline{Proc}_A^0$ i) = <d^1, c^1, ... $\underline{Proc}_A^0$ i> = $\underline{Exec}_A^1$ k,i.

2.5.3.3. A general memory can be applied to a qualified concept of R_i; $\underline{Proc}_A^1$ i ($\underline{Proc}_A^1$ l,i) = <e^1, f^1, ... $\underline{Proc}_A^0$ l,i> = $\underline{Exec}_A^1$ l,i.

2.5.3.4. A qualified memory (if it exists) can be applied to some (but not all) qualified concepts. If $\underline{Proc}_A^1$ k,i is distinct from $\underline{Proc}_A^1$ i then it can be applied to at least one concept: generally, there are specific pairs k,l for which the following operation is executed.

$\underline{Proc}_A^1$ k,i, ($\underline{Proc}_A^0$ l,i) = < h^1, g^1, ... $\underline{Proc}_A^0$ r, i >
= $\underline{Exec}_A^1$ l,r,i

The index, r, of the production, may or may not equal the qualifying index of the original concept. Empirically it is rare to find $\underline{\text{Proc}}^0_A\, l, i = \underline{\text{Proc}}^0_A\, r, i$. But both qualified concepts do belong to the concept of R_i; that is $\underline{\text{Proc}}^0_A\, l$, in $\underline{\text{Proc}}^0_A\, i$ and $\underline{\text{Proc}}^0_A\, r$, in $\underline{\text{Proc}}^0_A\, i$.

2.5.3.5. Pursuing the bones of a theory (Chapter 2, Section 5) the general form of a memory is

$$\underline{\text{Memory}}_A\, i \triangleq \underline{\text{Rep}}_A\ (\underline{\text{Concept}}_A\, i) = \underline{\text{Rep}}^1_A\ (\text{Rep}^0_A(R_i))$$

which preserves the level superscript, of necessity.

This process is represented by the causal coupling in the left hand (or A) part of Icon 1 (and $\underline{\text{Rep}}^1_B\ (\underline{\text{Rep}}^0_B\ (R_i))$ by the right hand (or B) part.

2.5.4. If distinct participants agree about their memories of R_i (thus, $D^1_A(R_i) \Leftrightarrow D^1_B(R_i)$, this fact is represented by the cyclic provocative coupling in the upper or L^1 part of Icon 1.

Since the cycle is severed by the vertical cleft it can be represented by a command and question transaction whereby A tells B to reconstruct his concept of R_i or asks B how he does reconstruct his concept of R_i (by symmetry, also, whereby B tells or asks A to do the same thing). The precondition for this command, to reconstruct (recall or reproduce) at least one concept of R_i has, as its precondition, the existence of L Processor models (i.e. concepts) for R_i; that is of $\underline{\text{Proc}}^0_A\, i$ and $\underline{\text{Proc}}^0_B\, i$. Since $\underline{\text{Proc}}^0_A\, i$ and $\underline{\text{Proc}}^0_B\, i$ exist in an L processor, not in a modelling facility, they are not directly observable at an interface between A and B. But the L^1 explanations that constitute replies to $\underline{\text{EQuest}}^1_A$, or $\underline{\text{EQuest}}^1_B$, (Table 2) are observable as L transactions (saying how A or B reproduce their concepts of R_i). These transactions are detailed below in the context of a broader category; namely, the transactions characteristic of learning.

2.5.5. The L^1 analogue of the L^0 constructive operation $\underline{\text{Proc}}^0_A\, i$ (X) (in contrast to a reproductive operation or memory) is an act of learning a concept. To exhibit the process in isolation it is necessary to consider a situation in which participant A does not have a concept $\underline{\text{Proc}}^0_A\, i$ for R_i but does have concepts for all R_{jk} that occupy nodes $j_i, \dots j_{mk}$ in at least one of the $\underline{\text{Im Ent Set}}$ k,i of node i (occupied by R_i which is ostended on the occasion in question). In the CASTE facility this condition is obtained if node

i is not marked as being understood, but is ostended, whereas all nodes in at least one $\underline{\text{Im Ent Set}}$ k,i are marked understood.

2.5.5.1. A legal learning operation (i.e. a learning operation that can be interpreted in that facility) is

$$\underline{\text{Proc}}^1_A\, i\, (\underline{\text{Proc}}^0_A\, ji, \dots \underline{\text{Proc}}^0_A\, jmk) = \langle r_1, s, \dots \underline{\text{Proc}}^0_A\, i \rangle$$

Legal and thus interpretable concurrency occurs where $\underline{\text{Proc}}^1_A\, i$ operates upon a class of ordered preconditions corresponding to $\underline{\text{Im Ent Set}}$ k_1 i, $\underline{\text{Im Ent Set}}$ k_2 i, and so on.

This operation is also represented by the left hand causal connection of Icon 1 or (in the case of B) by the right hand causal connections of Icon 1.

2.5.5.2. The L^1 transactions of learning are obtained by severing the provocative coupling in the upper or L^1 part of Icon 1 for the case in which the precondition is $\underline{\text{Proc}}^0_A\, ji, \dots \dots \underline{\text{Proc}}^0_A\, jm$ (or its generalisation to a class of preconditions) rather than $\underline{\text{Proc}}^0_A\, i$. The transactions are represented by the command and question forms of Table 2 and are shown below in terms of commands or questions addressed by B to A which meet with responses or replies from A to B. The responses, being constructive operations in an L processor, are not directly observable at an interface but the explanations which constitute replies to the questions are observable as part of the L^1 dialogue and are one segment of a learning strategy (as in Chapter 4, Plate 6 or Plate 7).

The transactions may either be unqualified or qualified.

2.5.5.2.1. The unqualified transaction forms are $\underline{\text{Comm}}^1_A\, i = \langle A!, R_i/\underline{\text{Precon}}^1_i \rangle \rightarrow \langle r^1, s^1, \dots \dots \underline{\text{Proc}}^0_A i \rangle = \underline{\text{Exec}}^1_A\, i\ D^1_A(R_i)$ where $\underline{\text{Precon}}^1\, i$ is either $\underline{\text{Proc}}^0_A\, i$ (in case $\underline{\text{Comm}}^1_A\, i$ is a command to reconstruct) or $\langle \underline{\text{Proc}}^0_A\, ji \dots \dots \underline{\text{Proc}}^0_A\, jmk \rangle$ (in case $\underline{\text{Comm}}^1_A\, i$ is a command to learn).

$$\underline{\text{EQuest}}^1_A\, i = \langle A?\ \underline{\text{Expl}}^1 / R_i \rangle \rightarrow \langle \alpha^1, \beta^1, \dots \dots R_i \rangle$$
$$= \underline{\text{Expl}}^1_A\, i \equiv D^1_A(R_i)$$

where $\alpha^1, \beta^1, \dots \dots$ and so on are L^1 expressions comprehended by $D^1(R_i)$ (just as α^0, β^0, are comprehended by $D^0(R_i)$). They may either be parts of A's explanation of how he constructed $\underline{\text{Proc}}^0_A\, i$ (in case $\underline{\text{EQuest}}^1_A\, i$ asks "how did you recollect R_i?") or data obtained as information from $D^1(R_i)$ (in case $\underline{EQuest}_A^1 i$ asks "how do you learn a concept for R_i?").

2.5.5.2. The qualified transactions are as follows $\underline{Comm}_A^1 k,i = \langle A!, R_i/\underline{Precon}^1 k,i\rangle \rightarrow \langle p^1, q^1, \ldots \underline{Proc}_A^0 k,i\rangle = \underline{Exec}_A^1 k,i$; $D_A^1(R_i) \Rightarrow \underline{Exec}_A^1 k,i$.

A command to build a concept of R_i from the specific precondition $\langle \underline{Proc}_A^0 j,i \ldots \underline{Proc}_A^0 jkm\rangle$ or to reconstruct it by a specific method.

$\underline{EQuest}_A^1 k,i = \langle A?\ \underline{Expl}^1 k/R_i\rangle \rightarrow \langle 1, 1 \ldots R_i\rangle = \underline{Expl}_A^1 k,i$.

Namely, "how (specifically) do you learn your concept of R_i on this occasion" or (depending upon the precondition) "How did you reconstruct your concept of R_i on this occasion?"; both are transactions at level L^1 of L.

2.5.5.3. The unqualified commands and questions may be referred through a specific $\underline{Proc}_A^1 l,i$ to the general concept of R_i (namely $\underline{Proc}_A^0 i$) by directives of the form:

$$\underline{Comm}_A^1 l,i = \langle A!\ R_i \wedge \underline{Stat}\ l\ /\ \underline{Precon}^1 i\rangle$$

or

$$\underline{EQuest}_A^1 l,i = \langle A?\ Expl^1/R_i \wedge \underline{Stat}\ l\rangle$$

to yield the construction or the explanation of how to construct $\underline{Proc}_A^0 l,i$ so that $D_A^1(R_i) \Rightarrow \underline{Expl}_A^1 l,i$ and $D_A^1(R_i) \Rightarrow \underline{Expl}_A^1 l,i$. Thus, psychologically, you may be asked to learn in any way a particular concept, or to explain how you learned it (failure to do so will evidence your inability to entertain the specific concept not your inability to learn it): similarly if you have a specific concept you may be asked to reconstruct it in any manner or to say how you did so (failure will evidence falsity of the supposition that you had the specific concept in the first place).

2.5.5.4. In contrast, the qualified L^1 commands and questions may only be asked of certain definite kinds of specialised concept: that is only certain pairs l, k, are compatible. Using the subscript indices as they were used in Section 2.5.3.4 the result of demanding a reconstruction may be the same specialised concept ($\underline{Proc}_A^0 l,i$) or a possibility different specialised concept ($\underline{Proc}_A^0 r,i$; where r is not necessarily the same index as l) or no concept whatever.

These possibilities are symbolised

$$\underline{Comm}_A^1 l, k,i = \langle A!\ R_i \wedge \underline{Stat}\ l\ /\ \underline{Precon}^1 k,i\rangle$$

If the result is $\underline{Proc}_A^0 l,i$ then the pair of procedures $\underline{Proc}_A^1 k,i$ and $\underline{Proc}_A^1 l,i$ are called P/P compatible in the context of R_i; if the result (for r other than l) is $\underline{Proc}_A^0 r,i$ then $\underline{Proc}_A^0 l,i$ is *mutable* under $\underline{Proc}_A^0 k,i$ in the context of R_i; and, if the result is no concept, then $\underline{Proc}_A^0 l,i$ and $\underline{Proc}_A^0 k,i$ are said to be P/P *incompatible* in the context of R_i.

The same comments and definitions apply to the explanations elicited by a qualified question, asked in respect of a specific concept and a given topic relation.

2.5.5.5. Psychologically, even if you do have a specific concept, by token of which you can reconstruct it somehow and give an account of your reconstruction, it does not follow that you can reconstruct it by a particular method even though you may also give an account of the method, and use it with respect to some other concept. If you can do so, then the concept and the method are P/P compatible; if not, they are P/P incompatible; if a fresh concept is produced as a result, then the original concept is mutated by the method.

2.5.6. If the participants A and B ostending topic relation R_i on occasion n are in agreement about their concepts of R_i, and if they are also in agreement about their memories of R_i, that is, about how to reproduce their mutually agreed (not identical) concepts then they agree about stable concepts of R_i and are said to (mutually) understand R_i. If so, in the CASTE facility, the node i of R_i is marked as understood on occasion n.

The condition of understanding R_i is represented by Icon 1 in its entirety and is one way of filling the conversational skeleton.

This icon says more than the equations taken in isolation. It says that the system of equations is stable under execution in an appropriate M Individual.

It represents the sprout or growing point of a strict conversation that is anchored on the topic relation (R_i) ostended on the nth occasion.

2.5.7. If (as is often prescribed in the sequel) the L^1 procedures of participant B are the execution of $D^1(R_i)$ and the L^0 procedures of the same participant are the execution of $D^0(R_i)$, then an understanding becomes, at the sprout, a correct understanding.

That is, an agreed L^0 explanation (or model) $D^0_A(R_i) \Leftrightarrow$ Some $D^0(R_i)$ is a correct explanation (or model), in the sense that it satisfies what may be done ($D^0(R)$).

Similarly, an agreed L^1 explanation $D^1_A(R_i) \Leftrightarrow$ Some $D^1(R_i)$ is a correct explanation in the sense that is satisfies what may be known ($D^1(R)$).

These comments apply, directly, to A but are symmetrical. It is more usual to call the B component, ($\underline{Exec}^0_B$) a demonstration (by modelling), as in Chapter 4 or a demonstrative explanation (taken as a stretch of L^0 dialogue) of R_i.

Similarly the B component ($\underline{Exec}^1_B$ i) is called advice on how to learn if it is tendered permissively, or a teaching strategy, if it is a mandate.

Whenever it is prescribed that $\underline{Exec}^1_B \equiv D^1(R_i)$ and that $\underline{Exec}^0_B \equiv D^0(R_i)$, this formula applies to $\overline{\text{all } R_i}$ in R. Hence for any locus of the sprout of a conversation, an "understanding" is a correct understanding.

2.5.8. From Section 2.2.3.2 (j) it is legitimate to augment Icon 1 by writing R in place of R_i (so that the sprout of the conversation may rest on any topic relation in R) and by introducing any legal proliferation of process boxes and connections that retains stable understanding of whatever R_i in R is ostended on a given occasion. For example, Icon 2 is legitimate. Since the connections around the central cleft assert that the system maintains understanding at the central cleft, restrictions are thereby imposed upon the contents of the unlabelled process boxes in participant A. Such proliferated constructions are henceforward given the generic label π if they are, or form part of, a (self-reproducible) P Individual.

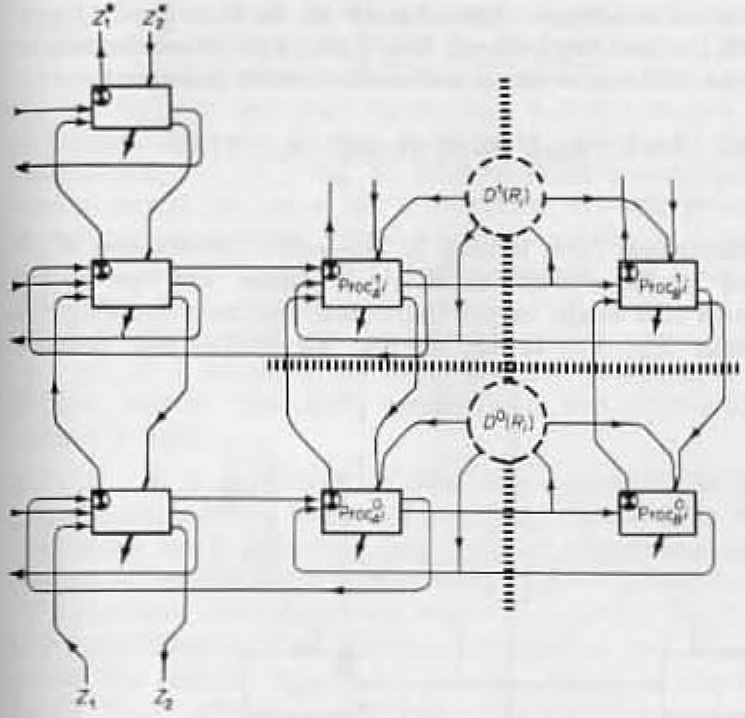
2.5.8.1. One obvious way to obtain a π that is a P Individual is to extend the general representation of concepts, memories, etc. by one further stage. That is, to move from

$\underline{Concept}_A\, i \triangleq \underline{Rep}^0_A(R_i)$

$\underline{Memory}_A\, i \triangleq \underline{Rep}^1_A\ (\underline{Rep}^0_A(R_i))$

to

P Individual $\triangleq \underline{Rep}$ (Memories (R_i))



Icon 2.

The following constructions are legitimate for any P Individual A in domain R_i or R

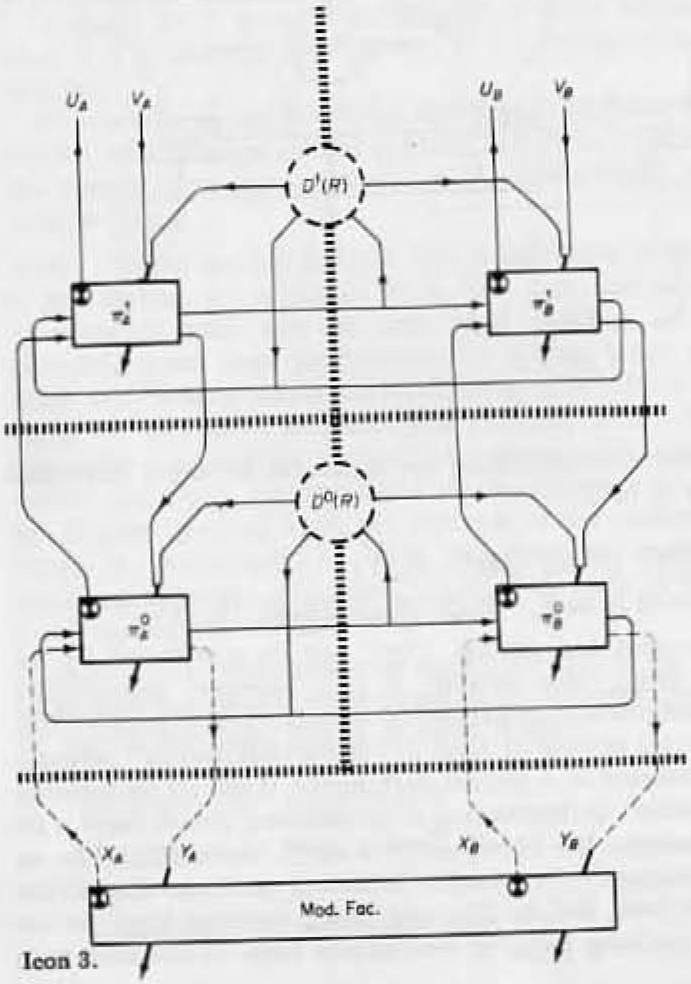
"$\underline{Rep}^0_A$ ($\underline{Rep}^1_A$ ($\underline{Rep}^0_A$ (R_i)))"

"For all R_i in R; ($\underline{Rep}^0_A$ ($\underline{Rep}^1_A$ ($\underline{Rep}^0_A$ (R_i))))"

in the sense that the general "$\underline{Rep}$" can be substituted by the $\underline{Proc}^0_A$ and $\underline{Proc}^1_A$ that execute it (for example, reproductive tesselation automata, populations of reproductive automata). But the reproductive process (a kind of "self-understanding" perhaps) cannot be observed at a central cleft; hence, it cannot be detected as an event called understanding at an interface; hence, there is no way to demarcate the occasions of a strict conversation. As an orienting comment it is possible to detect understanding if the specificity of level lost by allowing $\underline{Proc}^0_A$ realising $\underline{Rep}^0_A$ to act upon $\underline{Proc}^1_A$ realising $\underline{Rep}^1_A$ as well as vice versa, is retrieved by a distinction of subscripts. Thus for all R_i in R; { $\underline{Rep_B^0}$ ($\underline{Rep_A^1}$ ($\underline{Rep_A^0}$ (R_i))) and $\underline{Rep_A^0}$ ($\underline{Rep_B^1}$ ($\underline{Rep_B^0}$ (R_i))) } is satisfactory in this respect, if the subsystems are interlocked for example by

$$\underline{Rep_A^0}\ (Rep_B^1\ (\underline{Rep_B^0}\ (\underline{Rep_A^1}\ (Rep_A^0\ (R_i))))).$$

The cannonical form is Icon 3. The entire conversation is a P Individual in the context of R. As it stands, any one of the participants also might be a P Individual (by back coupling the connections X_A, Y_A to U_A or X_B, Y_B to U_B, V_B; perhaps



Icon 3.

through a nexus of the kind in Icon 2). By definition, these reproductive couplings may not be observed but an alternative (again possibly indirect) connection can be observed (namely; X_A, Y_A to U_B, V_B and X_B, Y_B to U_A, V_A) if a further level of discourse (generally though improperly called L^2) is added. Alternatively X_A, Y_A, X_B, Y_B may penetrate a modelling facility liberal enough to act as an L Processor but this possibility is prohibited deliberately. There is also a sense (to be discussed) in which, if A and B are in continual agreement, if B is designed so that $\underline{Proc_B^1}$ in π_B^1 represents the execution of $D^1(R)$ and $\underline{Proc_B^0}$ in π_B^0 of $D^0(R)$ (so that any agreement is correct agreement) then B can act as a surrogate for the replicative processes in A and, further, ensure that both construction and reproduction are correct or legal.

2.5.8.2. It is opportune, at this point, to clarify or justify a superficially perverse feature of Icon 3. As stipulated by this Icon, everything the P Individual does must be a modelling operation; the model constructed is subsequently executed under the control of a processor clock associated with the modelling facility (or, in our more liberal but less tractable formulation, may be executed, under the control of several processor clocks, as the model is built). The P Individual never reacts; only institutes procedures for execution.

However, as commented in Footnote 5, Section 1.7.1, the expedient of seeing things in this way is quite deliberate. If "I" (the participant P Individual) perform a skill the desired and logically defensible interpretation of this statement is that "I" (as a P Individual) set up a model in whatever processor ("my brain", for example) is currently executing "me"; this model is executed under processor control; "my brain" has, in this particular respect, exactly the same status as any other modelling facility. In fact, by a specialised but often useful extrapolation of the argument we can regard a physical modelling facility like STATLAB as an extension of "my" processor that in some respects augments, in others restricts, the capabilities of this processor. By the same token, a motor car is an extension of the driver's (biological) processor and so, for that matter, are any of the "laboratories" discussed at some length in Chapter 9.

It is true, of course, that the transactions involved in setting up a model within the P Individual's biological processor cannot, in general, be observed as part of a strict conversation. This is so for two reasons which have already been considered. (a) Because the transactions do not cross the vertical cleft of a conversational skeleton (since no precautions were taken to ensure that they should do so) and (b) because (for most conceivable skills) the modelling facility (the brain) is a many clocked facility and the model is concurrently executed. But, for all that, the transactions are essential and the modelling facility is not different in kind from mechanical or electronic devices that either do exist or, in principle, may exist.

2.5.9. By one means or another the entire conversation is a P Individual in the context of R. From appendix F, this P Individual may be factored into components A and B which are productive but not necessarily reproductive in B, such that one of them (A) is a self-reproducing P Individual in the context of $<B, R>$ and the other (B) may or may not be[12].

Special interest is attached to the circumstance under which one factor (B) is not self-reproducible (hence not a P Individual) and the other (A) though self-reproducing in the context of $<B, R>$ is not self-reproducing in the context of R. If so, B is called the support of the conversation and is denoted $S_B = <S_B^1, S_B^0>$, whereas participant A is ascribed the original notation, $\pi_A^1 = <\pi_A^1, \pi_A^0>$.

2.5.9.1. Consider participants A, B, in strict conversation about conversational domain R and over occasions $0, 1, \ldots n, n+1, \ldots N$.

2.5.9.2. If there is understanding at the sprout of this conversation upon occasion n then $n \rightarrow n+1$.

2.5.9.3. At occasion n, and subject to a caveat to be introduced in Subsection 2.5.9.6 below, let π_A^0 stand for A's repertoire of L^0 concepts ($\underline{Proc}_A^0 i$) up to the nth occasion as well as certain primitive operations, $\underline{Prim}^0$, deemed common to any conceptual repertoire, and needed to construct models or explanations in the first place (*Match* of Section 1.7.6 is one, and perhaps the only, $\underline{Prim}^0$). For any R_i in R that is ostended to anchor the sprout,

[12] The case in which neither factor is reproducible in R is excluded for psychological reasons only. A pair of factor subsystems S_A, S_B (rather than π_A, π_B) have inherent interest if their combination is a P Individual in the domain R. (We shall use this construction, with certain added connections, and the evolutionary form of domain $R = R(n)$).

$\pi_A^0(R_i) = \pi_A^0 i$ and $\pi_A^0 i$ is in π_A^0. This statement is to be interpreted "If π_A^0 operates on R_i at occasion n, then at or before occasion n + 1, the stable product $\pi_A^0 i$, is in π_A^0".

2.5.9.4. At occasion n, and again subject to the caveat of Subsection 2.5.9.6 below, let π_A^1 stand for A's repertoire of L^1 concepts (alias memories $\underline{Proc}_A^1 i$) up to the nth occasion, as well as certain primitive operations, $\underline{Prim}^1$, deemed common to any cognitive repertoire, and needed to construct concepts in the first place. For any R_i in R that is ostended to anchor the sprout $\pi_A^1(\pi_A^0 i) = \pi_A^0 p$ and (in the previous sense) $\pi_A^0 p$ is in π_A^0.

2.5.9.5. The $\underline{Prim}^0$ are isomorphic to some or all of the $\underline{Prim}^1$. The $\underline{Prim}^1$ are L^1 procedures corresponding, isomorphically, to the relational operators (Chapter 4) which are the external observer's L* descriptions of operations that carry one or more R_i into some other R_j in R.

2.5.9.6. The promised caveat is as follows:

(a) Call the P/P incompatibility of Subsection 2.5.5.4, an inter-level P/P incompatibility.

(b) Generalise the notion, to encompass intra-level P/P incompatibility, between procedures at level L^0 or procedures at level L^1, which, in psychological terms is interference.

(c) No $\underline{Proc}_A^0 i$ added to π_A^0 is intralevel P/P incompatible with an existing L^0 procedure.

(d) No $\underline{Proc}_A^0 i$ added to π_A^1 is intralevel P/P incompatible with an existing L^1 procedure.

2.5.9.7. To secure this "no destructive interference" condition the conversational domain is structured and L described to satisfy the constraints already imposed upon $D(R) = <D^1(R), D^0(R)>$ and B is designed to secure the integrity of A, which may either be stated as "continued understanding of topics in R" or as "the existence of a P Individual π_A in the context of S_B and R".

2.5.10. The experimental contract (Section 1.1 and 2.1) may be expressed operationally either as a structure that specifies A as "designed to learn" i.e. as "A student" or as a set of conditions obeyed by A and countered by B.

2.5.10.1. Participant A is party to the following contractual regulations (a) If $\underline{Comm}_A^0$ is issued and if $\underline{Precon}^0$ is satisfied then the command is obeyed; otherwise if $\underline{Comm}_A^0 i$ cannot be obeyed (no $\underline{Proc}_A^0 i$ or no $\underline{Precon}^0 i$) then $\underline{Comm}_A^0 i$ is interpreted as

$\underline{Comm}^1_A$i. (b) If $\underline{Comm}^1_A$i is issued (either directly or by interpretation of $\underline{Comm}^0_A$i) then, if $\underline{Precon}^1$i is satisfied, then $\underline{Comm}^0_A$ is obeyed to produce $\underline{Proc}^0_A$i so that $\underline{Comm}^0_A$i may be obeyed on a subsequent occasion. (c) For each $\underline{Comm}^0_A$i that is issued there is an attached $\underline{EQuest}^0_A$i that is (if possible) answered by an explanation. (d) For each $\underline{Comm}^1_A$i there is an attached $\underline{EQuest}^1_A$i that is (if possible) answered by an explanation. (e) It is possible to access $<D^1(R)\, D^0(R)>$ and the modelling facility according to the rules of L (for example, the CASTE language).

2.5.10.2. For his part, B agrees (or is designed) to satisfy the following constraints: (a) At any occasion n, to issue some $<\underline{Comm}^0_A$i, $\underline{EQuest}^0_A$i$>$ thus ostending some R_i. (b) If understanding of R_i is detected, to mark node i as understood and to execute $n \rightarrow n+1$. (c) Not to issue $\underline{Comm}^0_A$i*, $\underline{Equest}^0_A$i* on occasion n, if node i* is marked as being understood on occasion n. (d) To issue $<\underline{Comm}^1_A$i, $\underline{EQuest}^1_A$i$>$ on the nth occasion only if $\underline{Precon}^1$i; is satisfied (that is, if and only if, for at least one k, all of the nodes in $\underline{\text{Im Ent Set}}$ k,i are marked as being understood. (e) To take $\underline{Proc}^0_B$i $\Leftrightarrow$ Execution of $D^0(R)$ and $\underline{Proc}^0_B$i $\Leftrightarrow$ Execution of $D^1(R_i)$, for all R_i in R. (f) To furnish demonstrations (Section 2.5.7) or advice (Section 2.5.7) by way of co-operation, if they are requested by A, but to insist upon eliciting either $\underline{Expl}^0_A$i or $\underline{Expl}^1_A$ that do not copy the demonstrations or advice furnished.

2.5.10.3. To instrument this arrangement in the CASTE facility the transactions in Table 2 are restricted to those in Table 3. Though the student (A) is able (Table 2 of Chapter 4) to ostend any topic relation that is legal.

2.5.10.4. Under that constraint, B is a support $S_B = <S^1_A, S^0_B>$ and the construction for B, if embodied in an appropriate M Individual, is a cognitive reflector that literally mirrors the cognition of A; that is, B is a CET heuristic.

2.5.10.5. To represent this construction the right hand entries $<\pi^1_B, \pi^0_B>$ in Icon 3 must be changed to $<S^1_B, S^0_B>$. The construction is important enough to merit detailed attention.

From the point of view of an external observer, the otherwise neutral support, B, is a device that externalises the cognitive operations of A. Thus, if A and B are executed in distinct M Individuals α and β where β also embodies the interface, then B draws out all cycles of understanding relevant to R, so that their A component (normally unobservable if executed in α, as A's brain)

TABLE 5.3
The Command and Question transactions of a Strict Conversation controlled by a CET heuristic. A relinquishes the right to issue direct commands or questions to B and is furnished with statements of intent which if accepted as legal by B, serve as surrogates for $\underline{Comm}^1_B$; $\underline{Comm}^0_B$, $\underline{EQuest}^1_B$; $\underline{EQuest}^0_B$(in particular A executes $\underline{Exec}^1_A$ or $\underline{Exec}^0_A$ and B is in a position to give explanations (that is, demonstrations). These demonstrations may or may not be given. This depends upon cooperative transactions that modify A's prevalent intention (Section 3.4 and Table 2).

		Commands	Questions	Executions	Explanations
L^1	Base	$\underline{Comm}^1_A$ i	$\underline{EQuest}^1_A$ i	$\underline{Exec}^1_A$ i (Learning strategy)	$\underline{Expl}^1_A$ i
		Aim i	Aim i	$\underline{Exec}^1_B$ i (Ent Set display)	Cooperative Transactions
	Qualified	Tagaim i accept Tagaim	$\underline{EQuest}^1_A$ ji	$\underline{Exec}^1_A$ ji (Learning strategy)	$\underline{Expl}^1_A$ ji
			Tagaim i	$\underline{Exec}^1_B$ i (Ent Set display)	Cooperative Transactions
L^0	Base	$\underline{Comm}^0_A$ i	$\underline{EQuest}^0_A$ i	$\underline{Exec}^0_A$ i	$\underline{Expl}^0_A$ i
		Goal $ji_k jm_{ki}$	Goal $ji_k jm_{ki}$	$\underline{Exec}^0_B$ i (Demonstration)	Cooperative Transactions
	Qualified	$\underline{Comm}^0_A$ ji	$\underline{EQuest}^0_A$ ji	$\underline{Exec}^0_A$ ji	$\underline{Expl}^0_A$ ji
		Subgoal ji	Subgoal ji	$\underline{Exec}^0_B$ ji (Demonstration)	Cooperative Transactions

are executed, instead, in β; as a result of which they become observable. From A's point of view the support, B, looks like a co-operative agent that (supposing he has not already learned R) helps him to come to grips with this conversational domain, but, because of its neutrality, which does so on his terms. B does, of course, learn as A does. Strictly, it learns about A in the context of R (or, equivalently, R in the context of A) and it acts as the complementary converse of A in the conversational domain of R.

It is, in fact, a reflector that performs the following (equisignificant) operations: (a) B mirrors A in the context of R and (b) B also does whatever is needed in order that A shall understand R.

2.5.11. Without changing the right hand entries in Icon 3 (leaving $<\pi^1_B, \pi^0_B>$ as they stand) the icon represents an L conversation between P Individuals A, B, on the topic of R. The construction is quite general.

2.5.12. People often perform the role of a cognitive reflector without realising it; motivational research workers leading discussion groups or catalysing unstructured interviews are typically adept at the art of playing the role. In this case, however, there are two processors each capable of housing a P Individual and it is, perhaps, more convincing to cite an example in which the "other" processor is so degenerate that no conniving is possible.

My favourite instance is whimsical, but by no means facetious. The "other" processor is literally a physical mirror; a looking glass or shaving mirror.

First, distinguish ordinary ties (the sort I used to wear) from bow ties (the sort I wear now; the genuine article, not one of the made-up-beforehand kind, held on by elastic). For physical reasons that are obvious when you perform the task, the concepts $\underline{Proc}^0$i (tying an ordinary tie) and $\underline{Proc}^0$j (tying a bow tie) are P/P incompatible and interfere under execution. It is also true that these concepts (skills, perhaps) are usually learned and reconstructed (by $\underline{Proc}^1$i and $\underline{Proc}^1$j) which operate upon descriptions of $\underline{Proc}^0$i and $\underline{Proc}^0$j consisting in images of the motor actions involved in executing the concepts (skills) of tie tying. At any rate, this is so in my case.

I learned ordinary-tie concept ($\underline{Proc}^0$i) as a child; it is a well learned skill. But it is overlaid by bow-tie tying ($\underline{Proc}^0$j) which I learned later and often reconstruct (consciously, whenever I do-up the garment in front of a mirror, though I usually tie bow ties without visual feedback, using tactile feedback, only). On those rare occasions when it is necessary to wear an ordinary tie, solemn gatherings and the like, I am unable to execute $\underline{Proc}^0$i using tactile feedback only (as I used to do without effort). Moreover, given visual feedback from a mirror, I cannot immediately execute $\underline{Proc}^0$i; the first attempts are mere fumblings. But it is possible, though not without the mirror, to execute $\underline{Proc}^1$i and to

reconstruct $\underline{Proc}^0$i, quite deliberately. Moreover, once reconstructed, $\underline{Proc}^0$i is executed using only tactile feedback; no mirror is needed. One interesting further point is that $\underline{Proc}^0$i and $\underline{Proc}^0$j are incompatible. In the first place, and not too surprisingly, I find it difficult to tie a bow-tie having relearned ordinary-tie tying. Hence a mirror is needed to execute $\underline{Proc}^1$j and to reinstate $\underline{Proc}^0$j. The trouble is, given the mirror, it is quite hard to avoid executing bits of $\underline{Proc}^1$i, whilst $\underline{Proc}^1$j is carried out.

In this example the cognitive reflector is the mirror in which to see my limb movements. This element is necessary to execute $\underline{Proc}^1$i or $\underline{Proc}^0$j; that, in turn, depends upon seeing the execution of $\underline{Proc}^0$i or $\underline{Proc}^0$j. More generally the classical distinction between recognition and recall highlights situations that are valid examples of inanimate cognitive reflectors in action, though these are not usually so clear cut as tie tying.

According to the definitions introducted in the theoretical discussion, a memory is a reconstruction. The act of reconstruction is referred to as recall if the $\underline{Proc}^1$ is executed chiefly in the brain; recognition, if the $\underline{Proc}^1$ is executed chiefly in the environment which is structured or programmed to act as a reflector. This is true even of recognising a face and its name; the phenomenon is obtrusive in finding one's way through an imperfectly known city. Lots of memories are partly executed in the environment, many procedures are stored there.

In fact, personal environments are very often structured to act as cognitive reflectors: by the disposition of curios in a drawing room or souvenirs, as in my own study.

2.6. *M Individuation.* (Continuation of Sections 1.8.8, 1.8.9, 1.8.10).

Fig. 7 represents M Individuals independently of the procedures they execute. Different M Individuals are depicted by distinct blocks; different kinds of M Individuals are indicated by shading; the interaction between M Individuals is shown by abutment.

For the present discussion (as before) it is only essential to distinguish the following kinds of M Individual.

(a) Compatible L processors that execute procedures; these are labelled α, β.

(b) or (d) An interface, ι, also many clocked, that can act as a storage medium embodying the "hardware constraints" of computation theory and also as a limited L processor. $D(R) = <D^1(R), D^0(R)>$ is embodied in the interface as the pair

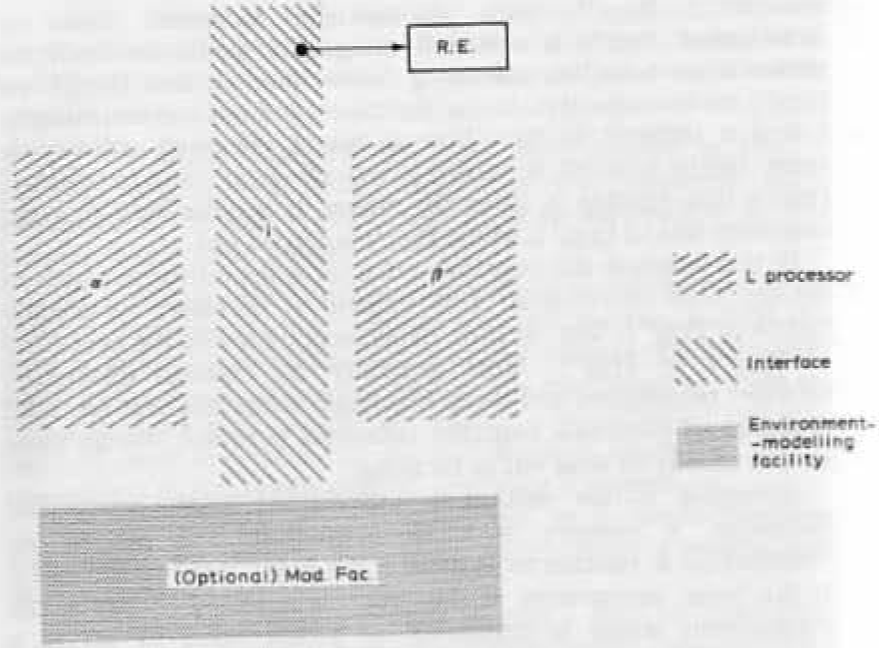


Fig. 5.7.

<Entailment Structure, Task Structure> or <ES (R), TS (R)>.

(c) A modelling facility either one clocked (Fig. 1) or many clocked (Fig. 2) constrained to execute models of a class, M, that is prespecified.

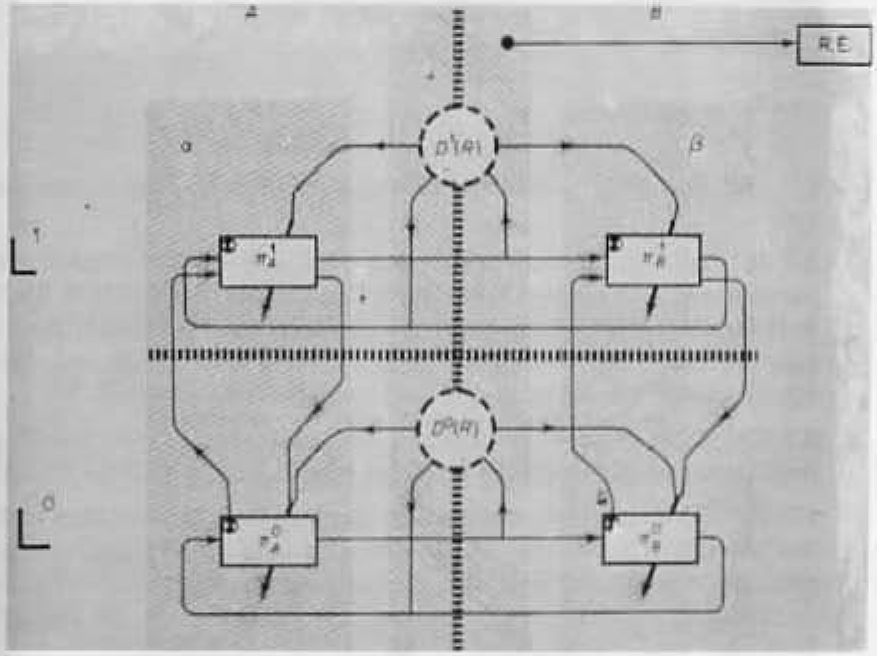
Both the interface and the modelling facility are objects that have a well defined spatio-temporal position and are able to execute certain types of procedure. An external observer's recording equipment is immutably bound to some spatio-temporal position. In this case, it is bound to the interface (of which the modelling facility, if used, is a specially restricted part). Insofar as the procedures that make up an understanding (Section 2.2.3.2) are executed in the interface they can be recognised in order to demarcate the ends of occasions in a strict conversation. The external observer can time an occasion with his stopwatch and thus determine its length (if the modelling facility has the restricted form of Fig. 1 then he can also time and order modelling operations and steps in model execution; generally, this condition is not satisfied).

2.7. *Embodiment.* To represent the execution of P Individuals at a definite place and time, the procedural icons 1, 2 and 3 are imposed upon the M Individuals of Fig. 7. A combination is permissible if the M Individual on which a procedure is superimposed is able to execute this procedure (for example, if a P Individual A is to be executed, locally, in one M Individual, then A can only be executed in α or β; as a convention A is assigned to α).

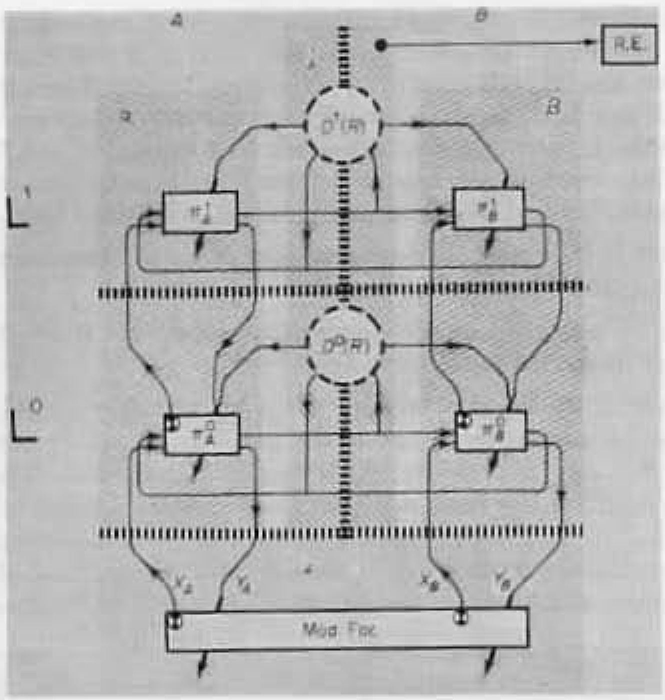
2.7.1. Icon 4 is the unique superimposition of Icon 3 (stripped of its modelling facility) upon Fig. 7.

2.7.2. Icon 5 is the unique superimposition of Icon 3 (augmented by its modelling facility) upon Fig. 7.

2.7.3. In Icon 6 the P Individuals $\pi_A = \pi_A^1, \pi_A^0$ and $\pi_B = \pi_B^1, \pi_B^0$ have both been replaced by supports S_A and S_B. To satisfy the requirement that any L conversation is itself a P Individual, it is necessary to establish the further connections shown in this icon (X_A to U_B, Y_A to V_B, X_B to U_A, Y_B to V_A). These constitute a different level of discourse in L, and since it is natural to think of them as discourse at a "higher" level, they are bundled together as



Icon 4.



Icon 5.

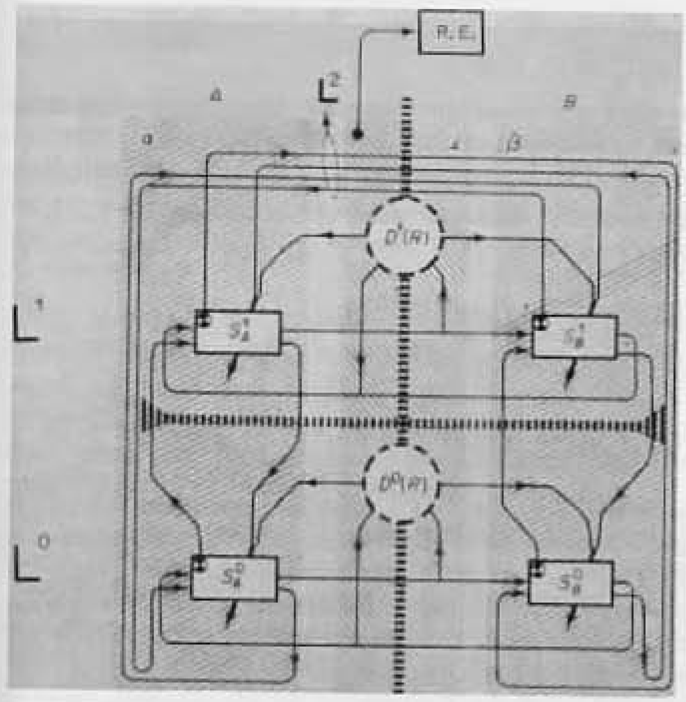
L². But this label is assigned on intuitive grounds, the others are not.

2.7.4. In Icon 7 one participant (B) is a support. The other participant (A) may be a P Individual and is labelled π_A. If A is a P Individual, the L² connection is unnecessary. Also notice that a support may be embodied in an interface although, in this construction, it is embodied in a compatible L-processor β.

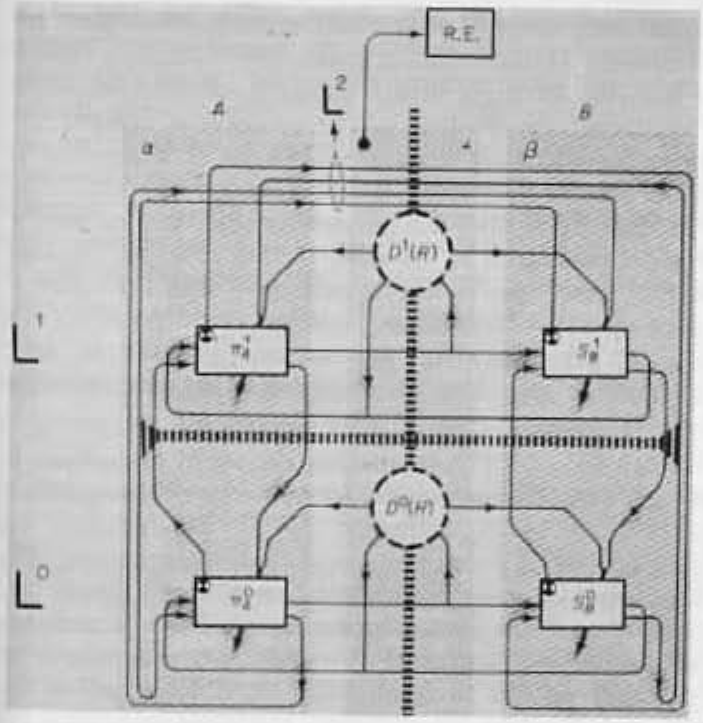
2.7.5. Thus Icon 7 represents the embodiment (or working realisation) of the cognitive reflector introduced in Section 2.5.10.

2.7.6. The connection across the central cleft is in register with the interface, ι, so that A, B dialogue can be recorded understanding recognised, and the occasions in a strict conversation demarcated. Further this conversation is anchored on the domain R.

2.7.7. Equivalently the (otherwise asynchronous) participants



Icon 6.



Icon 7.

A, B are partially synchronised, because of an information transfer symptomatised by the dialogue.

2.7.8. If B is a support (as it is in Icon 7) then for any strict conversation over a domain R and occasions 0, 1, . . . n, n+1, . . .n

$$\underline{\text{Prim}}^1 \subset \pi^1_A(0) \sqsubseteq \pi^1_A(n) \subset \pi^1_A(n+1) \sqsubseteq \pi^1_A(N)$$

and

$$\underline{\text{Prim}}^0 \subset \pi^0_A(0) \sqsubseteq \pi^0_A(n) \subset \pi^0_A(n+1) \sqsubseteq \pi^0_A(N)$$

2.7.9. This is a special case of a more general restriction, that applies to any P Individuals A, B, embodied in α, β and discussing a domain R. The restriction is manifest as *cognitive fixity.* A procedure, produced by learning or indoctrination upon occasion n, will be rejected from the repertoire $\pi^0_A(n)$ if it is P/P Incompatible (Section 2.5.5.4) with $\pi^1_A(n)$.

One demonstration of this property is as follows; first identify the procedures with general mappings (we may, since they are executed in specific M Individuals). Next, apply Ashby's (1962) habituation theorem to show that a trapping condition exists in which the reproduction of one class of procedures inhibits the reproduction of a different class *if the same P Individual* is executed in *the same M Individual.* Both clauses are important; for example, cognitive fixity does not necessarily beset two or more P Individuals under execution in the same M Individual and it does not necessarily beset the (distributed) execution of one P Individual over several M Individuals. However, cognitive fixity is a property of any M localised conversation (regarded as a P Individual). Much more elegant demonstrations are possible (Appendix F).

2.7.10. Knowledge of P/P incompatible classes of procedures is in a state of flux (for example, the work on programme equivalence referred to in Appendix F). In this chapter we concentrate upon one of many possible dichotomies; namely, the incompatible classes of holist strategies. Due to cognitive fixity, these strategy classes are mutually exclusive. It is important, however, to notice the limits of the exclusion principle. The exclusion principle applies to a particular A, B conversation on domain R. A and B might use different strategies in a different

conversational domain or conceivable on the same domain in a different conversation (or, in conversation with another participant C).

2.7.11. In the next chapter we shall examine the practical realisation of a support S_B as a CET heuristic executed by the CASTE facility.

2.8. *Measurement.* In general, an external observer who looks at a conversation has an unbounded uncertainty regarding where and when the procedures of this P Individual (and any P Individual within it) are undergoing execution. This "uncertainty of where and when" is the fundamental indeterminacy that hampers measurement by the usual "objective" methods[13].

2.8.1. In this respect an embodiment of the cognitive reflector in specific M Individuals α, β, and i is of special interest (Icon 7).

On the one hand, this construction minimally biases participant A (for example, it does not teach him in a particular way). The bias it does impose is summed up by its name; the "cognitive reflector" simply "reflects back at A" a self-image in the context of R. On the other hand (for this much impartiality) the arrangement minimises an external observer's uncertainty about where and when the procedures are being executed. The procedures underlying the observable A, B, dialogue (in the sprout of the conversation) are executed in α, β and (if the sprout is anchored on R_i occasion n) then they are addressed, on the interface, by index i. The procedures in question are executed in the course of occasion n (which has a stopwatch time tag) though it may be impossible to be more specific about their order of execution.

2.8.2. If these canons are accepted, the conversation is established as the proper unit for psychological enquiry; as proposed at the outset. This leads, of course, to a relativistic

[13] Since a reduction in uncertainty (in some sense) is equivalently an increase in information, care is needed to avoid confusion between the use of "uncertainty". This particular uncertainty (the external observer's, of where and when) has no direct or necessary connection with the subjective uncertainties H, H* (in Chapter 2, Section 4); A's uncertainties about aims and goals. Nor are either of these uncertainties, when expressed in terms of information, directly related to the information transfer which reflects synchrony between the execution of procedures in A, using β and corresponding procedures in B, using α.

psychology. A's concepts, memories, and so on are seen relative to a participant B and a conversational domain R; moreover, relative to the standard, though liberal, conditions that are maintained by B (either the CET heuristic or an interviewing role).

Because of that, the cognitive reflector has a family resemblance to the steady state technique (Chapter 1 and Chapter 2) and there is a specific identification that exhibits limitations of this technique; roughly, the SST is a reflector for one relation R_i assumed to be independent of others in R and the impoverished conversation that does take place has but one sprout and one occasion.

Chapter 6. Strict Conversations, Heuristics, and Classes of Experiment

In this chapter we describe the forms of strict conversations which take place under the CET heuristic (Section 1) and the uncertainty regulation heuristic (Section 2) in the CASTE facility. It would be possible to introduce the evolutionary heuristics, employed in the course assembly mode of operation at this stage. But, on balance, it is better to discuss the development of a conversational domain (when R is rewritten as R(n)) after detailing the structure of R and describing a verbally administered heuristic for generating a conversational domain. These topics form the subject matter of Chapter 7 and the evolutionary or course assembly heuristic is thus presented in Chapter 8.

Paradigms for various well known experimental situations are derived by imposing appropriate restrictions upon CASTE transactions. Thereby these experimental situations can be imaged, as strict conversations, within the facility. In practice, most experiments are not strict conversations but it is argued that the canons of good and informative experimentation lead the experimenter to approximate a strict conversation as closely as possible. Section 3 is an account of those experimental paradigms that can be derived from the CET and the uncertainty regulation modes; the other paradigms are described in Chapter 9 (general modelling, gaming, and game like interpersonal interaction) and in Chapter 11.

Finally, Section 3 goes slightly beyond this brief by presenting paradigms for the experimental situations of "personal construct" psychology (the elicitation of constructs, laddering, and so on). By this means, we introduce predication and operations that act on $D^1(R)$ or $D^0(R)$ as they are inscribed at the interface (thus replacing $D^1(R)$ by $D^1(R(n))$ and $D^0(R)$ by $D^0(R(n))$. Such domain-extending (predicating) operations are practically possible (repertory grids are widely used) and are essential in the argument of Chapter 7. However, they are not justified in terms of a mechanically executed heuristic until Chapter 8.